SURFACE ENVIRONMENT & MINING
SEAM
USDA FOREST SERVICE PROGRAM

USER GUIDE to HYDROLOGY

Mining and Reclamation in the West

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USER GUIDE TO HYDROLOGY

MINING AND RECLAMATION IN THE WEST

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
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Ogden, Utah 84401

RESEARCH SUMMARY

The hydrologist working on mined land must be aware of potential impacts of mining, as well as reclamation techniques available to him. This guide covers major points of concern to the hydrologist involved in planning for reclamation of mined land including: land-management planning and baseline data; soils and overburden analysis and sampling techniques; selecting storage areas; materials handling; spoils analysis; spoils problems/treatments; spoils surfacing; and monitoring and retreatment.

Information is presented in a question/rule/discussion format, and includes supporting graphic materials, notes on additional sources of information, a glossary, and an index.

ACKNOWLEDGMENTS

The contents of this guide are based on presentations and discussions during the Surface Environment and Mining (SEAM) sponsored Hydrology Workshop, March 21-23, 1979, Denver, Colorado. Credit is due all attendees and presenters for their input. Those who attended are listed in appendix B. In addition, major contributors are listed under chapter titles as appropriate.

A special note of thanks is extended to Earl F. Aldon, Ardell J. Bjugstad, Paul E. Packer, and Robert Partido, members of the cadre which planned the workshop. The workshop program coordinator was Edwin R. Browning (SEAM) and the technical adviser was Paul Packer.

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INTRODUCTION

MINERAL AND NONMINERAL RESOURCES

An adequate, reliable supply of minerals is essential to the economy and security of the United States, since minerals provide the physical basis for almost all activities of U. S. citizens. While imports can satisfy an important part of the country's minerals demands, they make the U.S. vulnerable to the economic and political decisions of foreign countries. Thus, the mineral deposits within the U.S. are a most important source of this nation's supply.

A substantial portion of the domestic minerals supply presently comes from lands managed by the Federal Government. Federal lands are known to contain a majority of the metallic minerals, as well as major resources of coal, oil shale, geothermal steam, uranium, and oil and gas. These same Federal lands, however, also contain valuable nonmineral resources, including timber, forage, water, wildlife, scenic landforms, and wilderness. The Government's holdings of such resources are now among the most significant in the world.

While it is clearly in the national interest to provide for the identification and production of the mineral resources on Federal land, it is also necessary to provide for a sustained high-level output of the various renewable resources on that land. Thus, the demand for mineral development must be balanced against the demand for renewable resources and the land-management agency's responsibility to reasonably protect the environment affected by mineral-related operations.

MINERALS IN THE LAND-MANAGEMENT PLANNING PROCESS

The Forest Service, as one of the agencies responsible for Federal land management, has a relatively sophisticated planning program for the management of nonmineral resources on land under its jurisdiction. Historically, however, the Forest Service's land-management and planning systems have treated minerals as a distinct category outside of the mainstream of the land-management planning process. There are two basic reasons for this separation:

1. The mining and mineral leasing laws have tended to make mineral activity the preferred use on any Federal land open to such activity. The thinking has been that on lands open to mineral activity, mineral development will generally override the designated primary nonmineral uses.
2. Planning for use of the mineral and nonmineral resources is complicated considerably by the difficulties of identifying and estimating the value of mineral resources. Mineral resources can be found only through costly and risky exploration. Therefore, land-management planning has tended to concentrate, at least until a mineral discovery is made, on the surface resource potential of the land.

The long-standing premise that mineral activity is always the most valuable use of a tract of land is increasingly being challenged. Many mineral deposits being discovered today are of lower grade, located at greater depths, and are therefore more expensive to find and mine than the high grade surface deposits formerly developed. Another significant factor is that nonmineral surface resources are not considered to be scarce, and their value has increased accordingly.

Hence, when all the mineral and nonmineral values are weighed for a particular proposal at a specific location, the value of the mineral resources may be outweighed by the value of the nonmineral resources. The process of weighing values usually occurs in an Environmental Assessment required by the National Environ-

mental Policy Act of 1969 (NEPA)[1] and is basic to determining the proper mix of uses for any given land area.

Given this situation of mineral and nonmineral values on the same tract of Federal land, decisions as to the proper use of a particular tract of land will always involve balancing the values of mineral and nonmineral resources. If this balancing is to be done in a reasonable manner, adequate information and analysis of all values are needed.

BACKGROUND: THE FORMATION AND MISSION OF SEAM

Realizing the complexity of such decisions, in 1973, the Forest Service chartered the Surface Environment and Mining program (SEAM) to coordinate research, development, and application related to land impacts resulting from minerals exploration and development in the West. From 1973 to 1979, SEAM sponsored more than 150 research and development projects. Together, the projects have greatly added to the body of knowledge surrounding the management of land in mineralized areas. (For purposes of this discussion, mineralized areas are defined as those areas that have some potential for mining.)

To get this knowledge to the specialists in the field in a form they could readily use, SEAM brought together researchers and users from industry, Federal agencies, and the academic community to share their practical knowledge and study results in a series of workshops. The information presented at these workshops is organized into five user guides. Each guide focuses on a specific discipline involved in managing surface resources that may be affected by mineral activities and is written for specialists in these disciplines. The guides will also be of use to land managers, land planners, and other specialists, since many activities related to minerals-area management demand that a variety of skills be applied to achieve an integrated approach.

In addition to the User Guide to Hydrology, guides have been written for vegetation, soils, engineering, and sociology and economics. Cross-referencing among these guides is provided in the index. A handbook for minerals specialists has also been written. A handbook for land managers will provide a general overview of administrative considerations surrounding mineral commodities commonly explored for and developed on national forest lands administered by the Forest Service. Concurrent with the development of the SEAM user guides, a USDA handbook on visual management related to mining and reclamation, entitled "Mining," is in press as volume 2 of the National Forest Landscape Management Series. A guide for the wildlife specialty is also planned. All guides will be updated periodically to keep them current with research findings.

The purpose of the guides is to help specialists more clearly understand their role in mineral exploration and development activities by outlining some of the major considerations they must address to insure that such activities integrate with land-management plans; that impacts are mitigated to a reasonable degree; and that reclamation meets state-of-the-art performance standards. Perhaps by using these guides as a common starting point, those involved in minerals management can more easily work together toward achieving these common goals: (1) appropriate consideration of minerals values in land-management planning; (2) protection of surface resources during mining activities; and (3) reclamation of surface-mined land to a productive use.

HOW TO USE THIS GUIDE

The chapters of this guide cover topics that concern the hydrologist during both land-management planning and any subsequent minerals activity. Within each chapter, major topics will be addressed in this way:

- Considerations: These are the questions the hydrologist should ask about each topic.
- Rules: These general statements answer the questions and direct the hydrologist toward the type of site-specific information the land

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[1] U. S. Laws, Statutes, etc. Public Law 91-190. [S. 1075], Jan. 1, 1970. National Environmental Policy Act of 1969. An act to establish a national policy for the environment, to provide for the establishment of a Council on Environmental Quality, and for other purposes. In its United States statutes at large. 1969. Vol. 83, p. 852-856. U.S. Gov. Print. Off., Washington, D.C. 1970. [42 U.S.C. 4321, 433-4335, 4341-4347.]

manager may need to make decisions. Rules are set in italic type.

- Discussions: The discussions explain the reasoning behind the rules and in some cases give specific examples of how the rules are applied.
- Exceptions: Exceptions to various statements are given where applicable.
- Additional Information: Here the reader will find basic references to further information on the topic discussed.

The aim of this format is to help define the role of the hydrologist in minerals management. The guide is not intended to be a "cookbook" on rehabilitation techniques. Rather, it is intended to set up a logical thought process based on a question/answer approach. Such an approach allows for flexibility, eliminates unnecessary data gathering, helps simplify technical decisionmaking, and allows for a systematic documentation of the decisionmaking process. We hope that this organization of material will make the guides equally useful to users in industry, Federal and State agencies, and the academic community.

The role of the Forest Service staff is illustrated in table 1, "Stages of Mineral Exploration and Development Activities," and table 2, "Roles of Forest Service Specialists in Minerals Activities," which follow this introduction. As you will note, the Forest Service hydrologist will advise, review, and monitor. For example, although fisheries monitoring takes place during all stages of mining, the hydrologist will review these plans when the operating plan is submitted prior to development and, if necessary, suggest revisions to the plan to improve reclamation potential. Then, during mining and reclamation, the Forest Service specialist will monitor these activities according to the approved operating plan. In this way, the effects of the development will be managed in a proactive, rather than reactive mode. In other words, rather than reacting to crises, the hydrologist will be part of the forest's interdisciplinary (ID) team from the time land-management planning begins. Then, if and when mineral activities occur, the team will have foreseen potential problems and will have determined general rehabilitation objectives in advance.

Both land-management planning, in its broader application, and site-specific operational planning for mineral activities on National Forest System lands require the full range of interdisciplinary efforts so that information on both the mineral and nonmineral values can be presented to the decisionmaker in an integrated manner. The interdisciplinary approach to planning is uniquely suited to giving the best available assessment of the spectrum of opportunities and problems of managing surface resources that may be affected by mineral-related operations and the requirements needed for reasonable protection of nonmineral resources. Soils, vegetation, hydrology, topography, geology, wildlife, climate, and social and economic information are some of the factors that must be considered by the ID team.

Land management and planning must always proceed on the basis of existing information. In the case of mineral resources, this will almost always be difficult because the mineral resources are hidden beneath the surface and information is provided in increments as exploration proceeds. One of the principal goals of Federal land management, therefore, should be to improve such management by obtaining better mineral-resource information and integrating it into the decisionmaking processes.

When using this guide, the reader should keep in mind that, for the most part, the information is concerned with scientific considerations. While other factors, particularly cost and legal constraints, are a crucial part of the planning process, discussion of these aspects is limited here.

One final note: Successful rehabilitation is as much an art as a science. To clarify specific points or to keep up with new developments, readers are urged to contact the researchers who contributed to this guide or their regional reclamation specialists.

Additional Information:

For more information on the mining process, refer to "Anatomy of a Mine," USDA For. Serv. Gen. Tech. Rep. INT-35. 1977. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Table 1. — *Stages of mineral exploration and development activities*[1]

Prospecting	Exploration	Feasibility studies/operating plan
A. Administrative Action No administrative action required; however, some evidence of mineralization or a hunch	A. Administrative Action Permit/Lease Notice of intent from miner (for certain commodities, may also serve as operating plan if there is minimal surface disturbance) Exploration license EA may be necessary See Handbook for Land Managers (in press) for variation within commodities	A. Administrative Action Submission of necessary permits (EA, EIS, etc.) and operating plan—see Handbook for Land Managers (in press) for variation within commodities
B. Activities Literature search Geological inference Evaluation of existing data Research on rights to land/minerals	B. Activities More intensive literature search Access road construction On-site testing and evaluation of data—geological, geochemical, geophysical, drilling, sampling, shaft sinking Seismic activity Acquiring land/mineral rights Rehabilitation of exploration impacts Environmental and socioeconomic studies	B. Activities Feasibility studies Grade and size of deposit Cost of mining and rehabilitation Market Fiscal Technical studies—mine design Environmental and socioeconomic studies (if not done during exploration) Decision to proceed with development Preparation of operating plan including rehabilitation program and end use Ordering of equipment
C. Environmental Impacts Minimal, if any	C. Environmental Impacts Roads Drill holes Drill pads Dozer holes Exploration camps	C. Environmental Impacts Generally none at this stage
D. Tasks for the Hydrologist Establish baseline water-quality monitoring as needed according to plan	D. Tasks for the Hydrologist Review of plans to reclaim land impacted by exploration Review and assist in hydrologic aspects of environmental studies	D. Tasks for the Hydrologist Review adequacy of operating plan for: Hydrologic considerations— surface water subsurface water snow management roads impoundments mine drainage Hydrologic aspects of end use

[1] The various phases have considerable overlap. The material provided for each phase is illustrative, not complete, and considerable variation is found by commodity. The existence of a forest plan is assumed. Tasks (D) are primarily input from a land-management agency's hydrologist. For purposes of discussion, the terms reclamation and rehabilitation are used interchangeably, and mining includes oil and gas activities.

Development[2]	Mining/reclamation	Postmining
A. Administrative Action Approval of necessary operating plan	A. Administrative Action No administrative action required. Mining overlaps with development and reclamation overlaps with mining; reclamation of previously mined areas occurs concurrently with new mining as stipulated in operating plan Any changes in operating plan	A. Administrative Action Release of reclamation bond
B. Activities Securing of financing More extensive testing and definition of the mineral Construction of transportation routes and utilities Construction of mine and processing plant (facilities, water supply, etc.) Construction of waste deposits Continued evaluation of data Change mining plan if necessary	B. Activities Extraction of mineral Processing of mineral Depositing wastes Operation of transportation systems Rehabilitation Monitoring for any changes in biological and physical environment Amend mining and rehabilitation plan if necessary	B. Activities Surface owner manages land after bond release Monitoring for any changes in biological and physical environment Management and maintenance for end-use objective
C. Environmental Impacts Mine Processing plant Waste dumps Transportation and access routes Utilities Increased population resulting from construction	C. Environmental Impacts Impacts directly related to operational aspects of mining; impacts are strongly affected by commodity mined and type of operation	C. Environmental Impacts Directly related to management and maintenance activities
D. Tasks for the Hydrologist Monitor impacts on hydrology	D. Tasks for the Hydrologist Monitor impacts on hydrology and hydrologic aspects of rehabilitation program Have hydrologic input into release of reclamation bond	D. Tasks for the Hydrologist Monitor any continued impacts on hydrology Manage hydrology for end-use objective

[2] Development is herein defined as the phase which begins after the right to mine has been established.

Table 2.—*Roles of Forest Service specialists in minerals activities*

	Prospecting	Exploration	Feasibility studies/operating plan
Vegetation specialist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in vegetation aspects of environmental studies	Review adequacy of operating plan for: Reclamation program — species selection plant materials site preparation planting methods cultural treatments Monitoring/retreatment program for vegetation Vegetation aspects of end use
Soils scientist	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in soils aspects of environmental studies Review soils inventory progress in the the mineralized areas; if needed, recommend timely completion or upgrading	Review adequacy of operating plan for: Reclamation Program— soils surveys storage area selection materials handling plans spoils analysis plan spoils treatments spoils surfacing and erosion control Monitoring/retreatment program for soils Soils aspects of end use
Hydrologist	Establish baseline water-quality monitoring as needed according to plan	Review of plans to reclaim land impacted by exploration Review and assist in hydrologic aspects of environmental studies	Review adequacy of operating plan for: Hydrologic considerations— surface water subsurface water snow management roads impoundments mine drainage Hydrologic aspects of end use
Engineer	None at this point	Review of plans to reclaim land impacted by exploration Review and assist in engineering aspects of environmental studies	Review adequacy of operating plan for: Engineering considerations— air pollution transportation facilities surface-mine facilities mine-waste disposal embankments tailings dams and impoundments subsidence Engineering aspects of end use
Economist	Monitor factors which affect supply and demand for minerals Make forecasts of supply and demand Predict probability	Analyze costs and benefits of alternative exploration methods Participate with the sociologist in identification of existing and emerging issues	Provide expertise in environmental analysis process: issue identification decision criteria cost/benefit analysis of alternatives tradeoff and opportunity-cost evaluations Analyze effects of development on: demand for surface resources human behavioral patterns community economics
Sociologist	Identify the basic social/cultural descriptors of the affected communities Note current trends	Assist in structuring public involvement plan for appropriate: issue identification issue analysis mitigation action Identify critical trigger points from a social perspective	Provide expertise in environmental analysis process: decision criteria issue identification Analyze effects of development on the cultural and political community Consider effects of alternative plans on social well-being

Development	Mining/reclamation	Postmining
Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary	Monitor vegetation impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a vegetation standpoint on release of reclamation bond	Monitor any continued impacts on vegetation Manage vegetation for end-use objective
Monitor impacts on soils Monitor soils-related activites for conformance to operating plan. Advise on plan revisions when necessary	Monitor soils impacts and activities for conformance to operating plan. Advise on plan revisions when necessary Advise from a soils standpoint on release of reclamation bond	Monitor any continued impacts on soils Manage soils for end-use objective
Monitor impacts on hydrology	Monitor impacts on hydrology and hydrologic aspects of rehabilitation program Have hydrologic input into release of reclamation bond	Monitor any continued impacts on hydrology Manage hydrology for end-use objective
Monitor engineering-related activities for conformance to operating plan Advise on plan revisions when necessary	Advise from an engineering standpoint on release of reclamation bond	Monitor any continued impacts from engineered structures Manage structures for end-use objective
Record costs Monitor economic changes	Record costs Monitor economic changes	Monitor to determine accuracy of predictions for future use
Monitor Record changes Identify areas of individual or group stress relating to mineral activity and make recommendations to mitigate effects	Monitor Record changes	Monitor and record critical changes to establish new baseline situation

Chapter 1

LAND-MANAGEMENT PLANNING, EXPLORATION, AND BASELINE DATA AND THE MINING PLAN

Chapter Organizer: Grant Davis

Major Contributor: Grant Davis

The hydrologist's role in mining operations begins before any mining activity occurs and continues during all the stages of mining, as well as after reclamation is complete and the bond released.

Because the hydrologic systems on a mine site can be affected during the very early stages of premining and exploration activity, the hydrologist's involvement actually begins even before interest in mining is expressed—during land-management planning. When exploration gets underway, his involvement increases. It is important to keep in mind that during mining, the hydrologist may not actively work with the hydrologic systems. The hydrologist, however, will be involved in reviewing mining plans and making decisions on their adequacy, so he must be knowledgeable about the conditions of the area and aware of what steps the mining operator must take to meet and maintain hydrologic standards.

This chapter looks at the early stages of the mining process—land-management planning, exploration, baseline data and the mining plan—and the role of the hydrologist in these stages. Remember that while the organization is roughly chronological, the stages are not clear-cut, and time overlaps may occur.

LAND-MANAGEMENT PLANNING

Long before a mining company expresses interest in a mineral deposit on land managed by the Forest Service, the land manager should know the area's potential for mining development, as well as its general reclamation potential. The hydrologist will play a key role in advising the land manager of the hydrologic impacts that may result if the area is mined, and of the area's reclamation potential. These considerations should appear in the general land-management plan.

Ideally, monitoring of hydrologic conditions begins during land-management planning. Budget and time restrictions, however, as well as the size of the area for which the hydrologist may be responsible, can make monitoring impossible at this time. Nevertheless, accurate and thorough hydrologic monitoring is essential over time for detecting changes in the hydrologic systems, taking mitigating actions to prevent damage to the systems, and maintaining hydrologic standards set by those governmental agencies regulating mining impacts. The hydrologist should be aware that, while standards are stated in terms of reclamation for soils and vegetation, for hydrology, standards address hydrologic conditions before, during, and after the mining process. The adequacy of a mining company's plan in addressing hydrology will be determined by the hydrologist, based on the information he has about the hydrology of an area, which may come from monitoring during land-use planning.

What is the role of the hydrologist in integrating hydrologic considerations into the land-management plan?

The hydrologist will be a member of an interdisciplinary (ID) team that will make recommendations on the land-management plan. If mining is a possibility, the hydrologist will provide information on the potential for protection or management of hydrologic values in the area during mining and their restoration after mining.

Discussion:

A high level of hydrologic information is usually not required during land-management planning, and the hydrologist is likely to rely on existing published and unpublished maps and surveys of the area or similar areas for information.

What hydrologic standards must be maintained during and after the mining process, and when are they set?

Hydrologic standards are set during land-management planning and, while specific hydrologic standards vary according to the mineral to be mined, and from area to area, the basic concept underlying all standard-setting is that the condition of the mined area should not be significantly different after mining than it was before. Thus, standards are designed to prevent the destruction of valuable aquifers and surface resources, as well as to allow mining companies to develop mineral resources. Hydrologic standards must be met for both surface water systems and subsurface water systems, so there is a need to relate the two.

Discussion:

Since standards will be site-specific, based on current land-management objectives and/or State standards, mining companies may consider requirements arbitrary and capricious because they differ from standards determined for a mining operation elsewhere or for other surface-resource uses. Presently, there are no specific guidelines for determining these standards, so a "reasonable" approach—one that protects valuable aquifers and surface resources and also allows for the development of mineral resources—should be taken. Eventually, a "reasonable" approach will be defined through the courts; however, until that time, Forest Service personnel involved in setting standards should maintain a written record of standards-setting procedures. This is so documentation of the process will be available if a court case is based on the procedure; under the new planning regulations, documentation on the part of the Forest Service is becoming important when legal issues arise. (See chapters 2 and 3 for specific hydrologic considerations in standards setting.)

Who sets hydrologic standards?

Agencies with the most authority to set hydrologic standards include the water-regulatory bodies of individual States; the Environmental Protection Agency, through the various States; Nuclear Regulatory Commission; Office of Surface Mining; and the Forest Service. Other government agencies may also develop standards related to the mining of specific minerals.

Discussion:

Though most hydrologic standards are set by agencies other than the Forest Service, the forest manager may determine at least some of the standards that should be met by mining companies; in these cases, the hydrologist will work with the forest manager to formulate the standards based upon identified needs.

What kind of hydrologic monitoring should be done during land-use planning?

Surface and subsurface water systems should be monitored in terms of water quality, the amount of water passing through the systems, who has the right to the water, and how mining might affect timing and delivery, water channels, lake shores, and lakes.

Discussion:

To determine whether a mining plan adequately addresses hydrologic monitoring, a hydrologist must have information about the condition of surface and subsurface water systems in an area, and this information, to be valid, must be collected over a long period of time. Thus, monitoring ideally begins during land-use planning. Climate variability, what is being monitored, and the reliability of the data being collected will determine the frequency of necessary monitoring.

EXPLORATION

Mineral exploration is the process of identifying and investigating "targets" in order to discover an economic mineral deposit. Exploration begins with regional studies that create little or no disturbance or occupation of the land. In addition to compiling existing geologic and photogeologic information, exploration also in-

volves geologic mapping and geochemical surveys. By the time a regional study has defined specific target areas, only a small portion of the lands originally considered is selected for more intensive study and exploratory work. At this stage, some land disturbance—drilling, for example—may occur.

Should a mineral deposit be found, the area of land involved is subject to more intensive exploratory work in a tighter pattern and is accompanied by more surface disturbance. If the exploratory work locates an ore body, development and mining are confined to an even more localized land area. Thus, a mining company's decision to explore an area for mineral deposits will require the land-management agency's personnel to become involved in a more intense analysis of the site than would normally occur during land-management planning.

How will the Forest Service hydrologist be involved with the mining company during exploration?

The Forest Service hydrologist will advise the mining company, through established agency procedures, of the hydrologic impacts of exploration and may or may not work with the mining company to collect data.

Discussion:

Early collection of hydrologic data on a potential mine site will help the hydrologist develop a data base for decisionmaking on the adequacy of mining plans and critical-area identification. As previously stated, hydrologic data must be collected over a long period of time to reflect such factors as seasonal variations. Working with mining companies to collect these data during exploration will increase the amount and extent of the data.

During exploration the mining company will be drilling to determine whether mineral resources exist and are minable. The hydrologist may be able to get water samples if an aquifer is tapped during drilling and he is working closely with the drilling crews. Also, the hydrologist may obtain information about rock strata from core samples, which could indicate an area's hydrologic suitability for mining, as well as information about the overburden.

Other kinds of information can be collected by the Forest Service during the drilling process, and the hydrologist may work as part of a team looking for several types of information.

Does the Forest Service have access to a mining company's data?

If a mining company has collected data about a leasable mineral, the company is required to give the Forest Service certain information about items such as mineral deposits. A prospecting permit may require the company to supply this information. A coal license absolutely requires this information of a mining company. For locatable minerals, any information collected is considered "privileged," and the company that collected it controls access to it.

Discussion:

Because mining companies have complete control of certain information they collect during exploration, prior data collection by the ID team is essential. The Forest Service should have information about every mine site on public lands, whether for a leasable or locatable mineral, because, in either case, it will be the responsibility of the Forest Service to insure that hydrologic conditions are not deteriorated or compromised during mining. In addition, a close working relationship between the Forest Service and the mining company, developed early in the mining process, can be beneficial to both parties since their combined expertise in data collecting can produce a more thorough data base.

BASELINE DATA AND THE MINING PLAN

Once exploration is complete and the mining company determines that it will mine the site, an environmental assessment may be in order and the formal gathering of baseline data to be included in the mining plan begins. Baseline data measure the conditions existing on the site prior to disturbance, help determine reclamation goals, and provide a basis against which reclamation success can be measured. Based on these comparisons, the mining operator may or may not be released from his bond of liability subsequent to mining and reclamation activities.

At this point, more specific information about the site may be needed to answer specific issues or management concerns identified in the

planning process. This information must be scientifically sound and well documented. In addition, ID team members should coordinate their efforts so that the data collected do not overlap.

General baseline data can be collected from field surveys as well as other sources of data, both published and unpublished, such as aerial photos and topographic maps. Information from these sources will generally include location of surface water features, topographic relief of the area being studied, aerial distribution of soils, surface geology, vegetation cover and distribution, magnitude and frequency of precipitation events, and stream flow and sediment discharge measurements. Further information must be acquired through monitoring.

The hydrologist will recommend to the land manager whether to accept, reject, or modify a company's mining plan, based on how the plan addresses hydrologic monitoring, and whether the company's plan includes measures designed to preserve hydrologic balances during the mining process and restore balances after the process is complete. The hydrologist may be responsible for proposing options to the mining plan either alone or as a member of an ID team. The land manager can request a periodic review of the plan during which changes can be made if: (1) mining processes are damaging hydrologic resources; or (2) only preliminary baseline data are included in the mining plan. To determine the adequacy of a mining plan's attention to hydrologic issues, the hydrologist must have valid data that have been collected over time, preferably showing seasonal hydrologic variations in the area.

What needs to be monitored and how often so that adequate hydrologic baseline data are collected?

The total ecosystem should be considered in monitoring and collecting baseline data. Such factors as water quality, delivery systems, channels, lake shores, lakes, how much water is passing through the system, who has the right to the water, and how mining will affect the timing, delivery, and total volume of water yielded from a natural system to one that is altered need to be inventoried so they can be evaluated according to their present condition and their condition over time. Climate variability, what is being sampled, and the degree of reliability of the data will determine those site-specific factors that should be monitored, and how frequently they should be monitored.

Discussion:

A conceptual hydrologic monitoring model or system should be developed by the mining company and evaluated by the hydrologist so that all information collected is relevant; only that information that fits into the model needs to be collected. This is an extremely important step for industry, because some mining companies collect too little baseline data, and some collect more than is necessary.

Who collects baseline hydrologic data?

Either the Forest Service or the mining company will collect the baseline data. Responsibility for data collection will be negotiated between the Forest Service and the mining company in each mining situation after exploration is finished and the company has made the decision to mine.

Discussion:

When the mining operation will be on Forest Service land, it is the responsibility of the land manager to determine if the mining plan has an adequate baseline-data design, and then if the data are collected according to the plan.

Although it is the responsibility of the Forest Service to insure that baseline-data requirements are met by operators on Forest Service land, in certain areas of the country, the Forest Service is considering allowing State agencies to enforce their own State requirements on National Forest System lands because these regulations are at least as stringent as Forest Service or Federal requirements. An example is the State of Wyoming. In these situations, the Forest Service will still approve mining plans and will retain authority over Forest Service lands.

In the case of small mine operators, extensive data collection may be economically unfeasible. To aid these operators, Federal assistance can be applied for through the Small Operators Assistance Program, Office of Surface Mining, U. S. Dept. of the Interior. This program was established by the Surface Mining and Reclamation

Act of 1977 (P. L. 95-87, 30 U.S.C., Secs. 1201 et seq.).

Who must gather the hydrologic information for environmental assessments if they are required?

If the operation is located on national forest lands, the forest supervisor may be required to provide the information, in which case the hydrologist will probably be involved in data collection.

Discussion:

The Forest Service hydrologist may be actively involved in data collection, or involved only in review of the data, depending on who must supply the data. In either case, the same kind of information is needed.

Additional Information:

For more information on baseline studies, refer to "A Systems Approach to Ecological Baseline Studies," Biological Services Program, Fish and Wildlife Service, U.S. Department of the Interior, FWS/OBS-78/21, March 1978.

For more information about hydrologic data collection, refer to Barrett, James and others. 1979. "Procedures Recommended for Overburden and Hydrologic Studies of Surface Mines, Thunder Basin Project." USDA For. Serv. Gen. Tech. Rep. INT-71. (In Press)

Chapter 2
SURFACE WATER

Chapter Organizer: Paul Packer

Major Contributors: Robert S. Johnston, Paul Packer, William S. Platts

Management of surface water at a mining operation is a primary consideration for the hydrologist, for while he will probably not be directly involved in such management, he must be in a position to review their plans and advise the mining company on appropriate steps. Thus, he must be knowledgeable about surface water resources, and how mining may affect them, prior to commencement of the actual mining operation. It is essential that the hydrologist have an understanding of water movement over the surface and through the topsoil and spoils from a number of perspectives: designing techniques to establish vegetation, controlling erosion, stabilizing spoils, and controlling water pollution. In addition, since restoring stream channels and fisheries to the natural state is very difficult and expensive once they have been altered, the hydrologist must be aware of how the mining plan will affect these resources. One of his concerns is with the intended future use of the stream for fisheries, and whether efforts are being made throughout the mining phase to insure that this and other uses will be possible.

This chapter covers water flows, both overland and in streams, and considers hydrologic management techniques for both controlled and uncontrolled flows. Potential reclamation techniques are covered in a later chapter in this guide.

What factors determine the hydrologic behavior of land?

Two of the most important factors are precipitation and solar radiation. These are called "uncontrolled inputs" because they are not subject to management prior to their occurrence.

Discussion:

Both the seasonal amount of precipitation and the proportion of precipitation that occurs as snow have a significant effect on the hydrologic balance. In areas of the Western U.S. where surface mining occurs, average annual precipitation ranges from less than 10 cm in parts of the desert coal fields in Arizona and New Mexico to more than 125 cm in mountainous areas. At this time, more detailed information is needed about the amounts, intensities, and return frequencies of precipitation that can be used as a basis for conceptual hydrologic models.

Solar radiation affects the hydrologic cycle mainly through its influence on temperature. Air temperature is dependent on a number of factors included in the heat balance of an air layer near the ground. The aspects of temperature and radiation balance that are important from the hydrologic standpoint are the length of the growing season, potential evapotranspiration, the proportionate amount of precipitation occurring as snow, and the frequency of freezing and thawing (i.e., frost-free growing days).

Temperature fluctuations are especially severe throughout the Western mining fields, with average annual freeze/thaw frequencies ranging from less than 50 in desert sites of the Southwest to more than 250 on alpine sites. High freeze/thaw frequencies accelerate weathering of overburden materials, and this substantially affects infiltration characteristics. Slope steepness, spoil characteristics, and aspects have a significant effect on microclimates, and hence on hydrology. South-facing slopes receive more solar radiation, reach higher surface temperatures, and have higher potential evapotranspiration rates than do north-facing slopes. This difference can affect, both directly and indirectly, surface and subsurface movement of water over and through mined spoils. Mulch can be used to mitigate the effects of solar radiation

temperatures; and, as a preventive measure, the impact of solar radiation should be considered when dump locations are planned.

What is the impact of evapotranspiration on the hydrologic budget of mine spoils?

The hydrologic budget for a soil or spoil mass includes terms for precipitation input to the mass and water loss from the mass through evaporation, transpiration, and deep drainage. The interplay of these factors can have an ultimate impact on surface runoff at the mine site, depending on the balance between input and output of water. Evapotranspiration can be modified drastically by surface mining, and this modification can, in turn, substantially alter the surface runoff regime.

Discussion:

When annual precipitation is compared to the total potential evapotranspiration for areas ranging from arid to humid, the following principles apply:

- In arid regions, total potential evapotranspiration exceeds the precipitation by a considerable margin. Here, plant cover commonly uses all of the precipitation in evapotranspiration and leaves virtually none for deep drainage.
- In humid regions, total precipitation may equal or exceed potential evapotranspiration by a significant amount. Here, an excess of water beyond that required to satisfy plant growth and soil storage may occur. This excess will eventually appear either as surface water in the form of stream flow and/or as an increment to the ground water table.
- In areas where winter precipitation accumulates as snow or as soaking rains, there may be significant deep percolation, even though evapotranspiration exceeds precipitation on an annual basis.

The actual rate of evapotranspiration depends on climatic factors, soil/water content, the extent and type of plant cover, and land treatment and management techniques. Evapotranspiration can be modified significantly by removing or replacing vegetation during surface mining and reclamation operations. This can significantly change the surface runoff.

What is the significance of infiltration characteristics to the surface water regime in mined areas?

Infiltration is the basic precursor to overland flow and surface runoff. As snow melts or rain falls on soil or spoil materials, two important characteristics, infiltration and storage capacities, govern the amount of water that will enter and be stored in the soils and spoils. These characteristics exert a controlling influence on the eventual amount of surface runoff.

Discussion:

Major factors controlling infiltration are pore size and pore size distribution characteristics of the top few centimeters of the spoils, and the chemical nature of these spoil surface layers. Porosity characteristics of the surface, the kind and amount of vegetative cover, and the rate and amount of rainfall and snowmelt, as well as some of the physical, chemical, and biological characteristics of spoils that affect infiltration can be manipulated by man through agronomic and engineering practices. Other factors that determine the rate and amount of infiltration are slope steepness and orientation of the site surface.

Since surface-mining disturbance can increase overland flow (discussed later in this chapter) by decreasing the infiltration rate of spoils, it is important to understand characteristics of infiltration.

Slope steepness and orientation have a substantial but indirect effect on infiltration, and are important factors in mountainous areas of the West. Depression storage is generally greater on gentle slopes than on steep slopes and surface water is present longer after rainfall stops, providing greater infiltration opportunity. Therefore, spoil dump slopes should be as gentle as possible to enhance infiltration. The orientation of spoil dumps can affect infiltration by controlling the accumulation and melt of snowpack and repeated freeze/thaw cycling (see discussion of freeze/thaw rates earlier in this chapter).

Exceptions: There are two general exceptions to this: (1) Spoil materials that have not previously been subject to freezing and thawing because of their premining position below the soil surface tend to break down physically under such exposure. The

result is that smaller particles decrease the hydraulic conductivity more rapidly than do topsoil materials that have been previously repeatedly exposed to freezing and thawing. (2) Frozen spoils usually have a lower infiltration rate than unfrozen spoils. Spoils can be protected from freezing by temporary mulching or the rapid establishment of a protective cover of vegetation and organic matter.

Drastically reduced infiltration rates are common on spoils with pH's of much less than 5 or much more than 9; these limits are usually exceeded on heavy-metal mining sites and on sodic coal and bentonite areas. Where the surface layer or spoil is different from the underlying material, the top layer may have a saturated hydraulic conductivity that is less than that of the material below. In this case, infiltration is almost completely determined by the hydraulic conductivity of the surface layer and the storage capacity is determined by the hydraulic conductivity of the underlying material (hydraulic conductivity of any material is determined by volume and distribution of pore sizes). Where the top layer has a saturated hydraulic conductivity that is greater than that of the material below, infiltration behavior will still be largely determined by the hydraulic conductivity of the surface layer, and the storage capacity of the surface layer will depend on that layer's pore space storage characteristics. These spoil characteristics need to be known before spoil dumps are built, and in some cases may be learned from drill cores; however, they will primarily be learned by testing during overburden excavation. From a hydrologic point of view, the characteristics of the overburden layers need to be known so that advantage can be taken of them in sequencing materials into spoils to achieve the hydrologic objectives established earlier.

Infiltration generally has been described or predicted based on empirical equations or simplifications of general equations. Equations presented by Horton and Holtan are examples of empirical models. Equations obtained from simplifications of basic equations or algebraic approximations of numerical solutions to the basic equations have been given by Smith, Mine and Larsen, and Brustkern and Morel-Seytoux. The major stumbling block in estimating infiltration is the necessity of estimating parameters. Holtan and others have attempted to develop techniques for estimating parameters by using information available in soil surveys or by developing estimates of parameters for various land use or cover factors. Direct measurements of infiltration rates and capacities obtained from rainfall-simulating infiltrometers have provided valuable information concerning the infiltration characteristics of different kinds of land subjected to various treatments.

How does mining affect surface runoff?

Surface runoff begins when rainfall or snowmelt rates exceed the infiltration capacities of soil or spoil materials, or when the quantities of rain or snowmelt water have filled the storage capacities of the soil or spoil materials. Inasmuch as mining does alter the infiltration capacity of soil and its storage-capacity characteristics, it also influences resulting surface runoff.

Discussion:

Surface runoff can be classified as either overland flow or channel flow. A definition of overland flow is that which occurs outside of the well-defined and previously-existing channel system.

The mean velocity of overland flow is *directly* related to the slope for laminar flow and to the square root of the slope for turbulent flow; mean velocity is *inversely* related to the hydraulic resistance of the surface. In other words, the rougher the surface, the slower the flow.

Hydraulic resistance varies widely, depending on surface roughness characteristics, ranging from a Mannings n of .02 for bare soils to about .4 for a dense grass turf. Differences in hydraulic resistance of this magnitude from bare soil to dense turf will result in the depth of water on the rougher surface being approximately 6 times as great as the depth on the bare soils for the same discharge. The velocity of overland flow on rough surface soil would be only 1/6 of that on bare soil. Thus, the greater water depth on the rough, dense sod would allow much more time for infiltration after rainfall stops, resulting in less runoff, even if the infiltration characteristics

of the sod cover and the bare soil were the same. The lower velocities on the sod will also result in a much lower erosion potential. In many cases, surface-mining disturbance will increase overland flow by decreasing the infiltration rate and reducing the hydraulic resistance of the surface. Decreased infiltration and reduced hydraulic resistance tends to increase peak flow rates reaching stream channels.

Increases in surface runoff from various kinds of surface-mined disturbances in the West have been observed and measured. As an example, at one site, the overland flows from a spoil dump without any vegetation on it were compared. The dump had been prepared for revegetation; half of it was topsoil covered and half of it was raw spoil covered. On each half of the dump were a dozen plots extending the full length of the slope, each equipped to measure runoff and erosion. A storm at this site produced some .4 in. of rain in a few hours. It was observed that about twice the overland flow occurred on the raw spoils than on the topsoiled area, showing that the topsoil had better infiltration and storage characteristics. In addition, the sediment production off the raw spoils was 10 times that of the topsoil—that is, twice the runoff from the spoil materials produced 10 times the amount of sediment than came from the topsoil. This example provides an indication of the hydrologic advantages of topsoiling. (It should be noted that the preceding discussion represents only one observed example, and further research needs to be done to establish guidelines relative to length and steepness of spoil pile slope versus a design storm.)

What is the impact of surface water storage on overland flow?

Water can be stored on a soil or spoil surface as depression storage, within soil in an unsaturated condition, or in a saturated form where an impermeable barrier prevents or reduces the rate of further downward movement. All water that is trapped as depression storage either infiltrates or evaporates, with infiltration usually being greater. Within limits, rougher surfaces provide more depression storage. Depression storage may become surface runoff, however, when surface depressions overflow. This can quickly create a breakdown in the entire depression storage system and cause extensive erosion, a phenomenon that must be prevented on surface-mined areas.

Discussion:

Prevention or reduction of depression storage system breakdown can be achieved by increasing the amount of surface storage. This is done by keeping the gradient of spoil dump slopes gentle and the surfaces rough. A caution is merited, however, because the advantages of doing this—better erosion control and vegetation establishment—must be balanced against the dangers of allowing too much subsurface water buildup in the interior of spoil dumps, thereby creating a mass failure hazard.

How is erosion related to overland flow?

Erosion begins when raindrops strike soil or spoil surfaces and detach particles from them. The particles are then available for transport by surface runoff. Shear forces exerted by runoff may also detach particles, resulting in further erosion.

Discussion:

On short slopes of perhaps no more than 100-200 ft in length, raindrop splash erosion is most significant. On longer slopes and in snowmelt situations, rill erosion as a result of overland flow becoming concentrated is more significant. Exceptions to this depend greatly upon stability characteristics of the soil and spoil material and steepness of the slope. Except for arid desert areas in the West, most of the erosion caused by overland flow is generated by snowmelt runoff, which occurs every year. Thus, bare soil areas should be protected by surface mulches and vegetation as soon as possible. Also, sediment basins should be designed to handle the larger quantity of snowmelt runoff that is anticipated. Where rainfall, rather than snowmelt, is the primary cause of erosion by overland flow, sediment basins should be designed to handle the high-intensity, short-duration rainstorm events that are expected.

What is the role of overland flow in chemical pollution of water from mine sites?

Chemicals dissolved in water will ordinarily move at approximately the same rate as the water, if the chemicals are not too highly reactive with spoil materials. Generally, anions,

such as chloride and nitrates, fall in this category. If, however, interactions occur between the dissolved chemicals in the spoil materials, many complex situations may occur. For example, cations such as calcium, magnesium, potassium, sodium, ammonia, copper, iron, and cobalt are highly reactive and will readily exchange on and off the spoil cation exchange sites.

Discussion:

A major effect of surface mining is the potential for concentration of salts and heavy metals in the runoff water, and thus, its potential impact on downslope and downstream water uses. In many cases, chemistry of mine spoil materials is such that soluble salts can keep overland flow water, and even stream flow below the spoil, near saturation with concentrations of saline, alkaline, acid, and heavy metal cations that are damaging or even lethal to terrestrial and aquatic biological organisms in their path. The concentration of heavy cations in water depends to a large extent upon the pH levels of the water, a partially-manageable spoil characteristic.

Additional Information:

For more information on chemical site preparation of soils and spoils, see "User Guide to Soils," INT-68.

For more information on equations, refer to:

Horton, R.E. 1940. An approach toward physical interpretation of infiltration capacity. Soil Science, Society America Proc. 5:399-417.

Holtan, H.N. 1961. A concept for infiltration estimates in watershed engineering. USDA Agric. Res. Serv. 41-51, Washington, D.C., 25 p.

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Mine, R.G. and C.L. Larsen. 1973. Modeling infiltration during a steady rain. Water Resources Research 9(2):384-394.

Brustkern, R.L. and H.J. Morel-Seytoux. 1970. Analytical treatment of two-phase infiltration. J. of Hydrology Division Proc. American Society of Civil Engineers 96(HY12):2535-2548.

STREAMS

Streams, defined as concentrated flows of water moving in a definable channel or natural drainage system, will be considered in this section. The hydrologist should keep in mind that streams need not be on mine sites to be affected by mining activity; rather, the local geology and land form of the area will determine the kinds of impacts a mine will have on on-site, as well as off-site, streams. Any type of vegetation removal, soil compaction, increase in slope gradient, and/or construction is likely to increase the volume of flow and rate of delivery or response time—the time it takes for water to move from spoils into a channel. These factors may also increase sediment loads, chemical or soluble loads, and peak flows (fig. 1). The most obvious effects of mining on stream flow occur as a result of such activities as construction of roads, pits, and dumps or terraces that intersect a natural drainage system. Indeed, roads may have a greater impact on the surface water flow than the active mine situation itself in terms of volume of flow, the number of drainages that are intercepted, and the total area disturbed. The hydrologist should be aware that any impacts on the channel surface or the water quality also impact the stream's aquatic environment.

This section examines some of the factors hydrologists should consider when faced with questions concerning stream characteristics.

What factors influence the physical stability of a stream channel?

The physical stability of the stream channel is a function of the texture, structure, and chemical nature of both the side and bottom materials of the channel together with the expected peak stream flow rate.

Discussion:

The stability of the channel will be affected by the gradients and the alignment of its boundaries. It is predictable that changes in the volume or rate of flow of water through the channel will impact sinuous streams more highly than straight channels. Moreover, engineering attempts at straightening stream channels to solve stability problems have been only partially successful to date. In addition, abrasion or corrosion of the sides and bottom of stream

Figure 1. Sediment load and movement in streams can be altered by mining activities and damage or destroy fisheries.

channels can be caused by erosion, which is a result of hydraulic action of the water or water-borne particles. Channel erosion may also be caused by chemicals present in the water (fig. 2).

What is the role of sediment basins in maintaining water quality in streams?

Sediment basins can serve to prevent degradation of water quality caused by sedimentation in the stream channels.

Discussion:

Sediment basins, while being of greatest use during the time between when mining starts and total revegetation of the area is completed, can continue to be useful following these measures, particularly if the stream flow regime in small watersheds is changed by mining. Presently, it is felt that the data base for the proper design, operation, and maintenance of sediment basins should be expanded to avoid failure in the basins.

How can in-stream problems be minimized?

The most important step in minimizing in-stream problems is to have a complete enough data base to be able to anticipate the types of problems that will occur at the mining site. This will enable the hydrologist to advise the mining company on how to design the mine or the water flow system to handle the expected problems. In addition, when problems are anticipated, the hydrologist can suggest several alternatives for solving them. Alternatives may be biological, which usually implies a long-term solution that may require maintenance; or problems may be solved through engineering design.

Figure 2. Bank slumpage, characteristic of stream instability, can be caused by erosion from the hydraulic action of water or chemicals dissolved in water.

Discussion:

A number of techniques are available to the hydrologist for helping to minimize in-stream problems. Foremost among these is enlisting the advice of an expert in river and stream mechanics. Economic constraints should always be considered in suggesting these techniques; however, in light of the maintenance/reclamation goals of the mining plan, these may be considered as possible alternatives for minimizing in-stream problems:

- Occasionally, it is beneficial to divert water from one natural channel to another. While this should be a last alternative because of its impact on the channels and fisheries, it is still useful when needed. For example, when roads are being built, water is often diverted from one drainage intercept to another. Diversions can also be used to route off-site water around disturbances and mine dumps, rather than allowing it to run through the disturbed area.
- Buffer strips can be used to prevent excess water and sediment from being dumped into active water channels. For instance, such strips are utilized on the Caribou National Forest, where any surface disturbance within 200 feet of a stream that has been designated as a high-value fishery is prohibited. Buffer strips should be used wherever needed. Guides are available for developing buffer strips along logging roads, and these could probably be adapted to mining situations.
- Engineering-type structures, such as energy dissipators and settling basins can be used to reduce sediment load. Technology is available for removing chemical loads from water, but the costs can be prohibitive, particularly at high-elevation or abandoned mines. Moreover, there

is no clear-cut definition of who is responsible for removing the pollutants.

• Stream channels can be stabilized by a variety of techniques—rip-raps, drop inlet structures, bank stabilization—which can be accomplished at the time slope gradients and stream bank slopes are changed, and vegetation is reestablished. Optimally, stream channel stabilization would be achieved by a combination of revegetation and engineering techniques.

STREAM FISHERIES

How does mining affect stream fisheries?

Mining can affect fisheries by widening or filling in stream channels, diverting stream flows, increasing suspended sediments and dissolved solids, disrupting stream banks, increasing sediment bedloads, eliminating or changing riparian vegetation species composition, and adding toxic elements to the water.

Discussion:

Monitoring the effects of mining on a fishery is difficult because the interactions between mining and the fishery are complex. Nevertheless, there are suitable monitoring systems in use that provide the necessary information to evaluate the effects on fishery habitats of management activity, in this case, mining. In dealing with fisheries on mining-impacted areas, the hydrologist should call on biologists to assist in suggesting the best methodology available. Legally, the Forest Service can use State and Federal water-quality regulations, as well as its own standards, to protect fisheries from mining impacts.

What should stream monitoring for mining impacts on fisheries include?

All four components of the aquatic system—stream-side vegetation, channel morphology, shape and quality of the water column, and the soil portion of the stream bank—should be monitored over time.

Discussion:

Stream monitoring may be a simple two-station operation—one above the mining activity and one below; or an elaborate network of many stations may be needed. The method selected will depend on the extent of anticipated hydrologic impacts from the mine, the overall hydrology of the area, and the nature of the surface water system. Fish are excellent monitoring tools because they are indicators of present aquatic conditions.

Stream-side vegetation. Certain types of stream-side vegetation biomass can be determined by using an electronic digital herbage recorder or by weighing. Occular estimates of biomass weight can also be useful, but accuracy requires continual training of the estimators checked against actual weights. Stream-side vegetation, along with undercut banks and stream-side debris, provide fish cover and stabilize water temperature. Vegetation also provides habitat for terrestrial insects, an important part of the fishes' diet. If stream-side vegetation is eliminated, so is a large segment of the fishery, regardless of excellent water quality or channel conditions.

Stream channel morphology. This can be monitored by using freeze method or core-type substrata samplers, which are fairly effective. Tract sediment and deposition can be monitored with transects and measuring rods. Substrata movement can be monitored with a chain system or other devices that indicate channel gradation or degradation (fig. 3).

Water column shape and quality. Standpipes are used to measure subsurface oxygen, subsurface water flows, and subsurface permeability (fig. 4). A thermister is an excellent temperature monitoring device for this. Occular measurement systems are now used to monitor stream channel changes, although observation error and repeatability are problems with this method. If measurements are large, however, the occular method is sufficiently accurate. High-quality water is essential to the survival of fish. While lethal levels of heavy metals and acid produced by mines can be easily monitored using standard methods, incipient lethal levels—amounts less than 10 parts per billion—are difficult to monitor. Current monitoring methods do not indicate incipient lethal levels, avoidance levels to fish, or obscure levels that react over long periods of time.

Soil portion of the stream bank. Cross-

sectional stream bank profiles are one of the better monitoring methods for the soil portion of the stream bank; stream bank stability, and vegetative cover and vigor ratings also help monitor stream bank conditions.

Since stream fisheries are complex environments, and specialized knowledge is required to manage them effectively, the hydrologist should seek the assistance of a fisheries biologist when working in this subject area.

Figure 3. Chain systems can be used to monitor substrata movement.

Figure 4. Standpipes are used to measure subsurface oxygen, subsurface water flows, and subsurface permeability.

Chapter 3
SUBSURFACE WATER

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Management of subsurface water is an important consideration during the mining process, both in terms of mining's impacts on existing subsurface water systems and in terms of systems that may develop as a result of mining activities. While the hydrologist probably will not be directly involved in their management, his knowledge of the potential impacts of mining on these systems can insure that proper management plans are included in the mining plan.

What information does the hydrologist need to describe a ground water system?

To describe the ground water system for a mining area in detail, information about the geology of the site and aquifers present on the site is needed. This can be obtained from existing information and wells, additional well samples, and installing new wells.

Discussion:

Aquifers must be identified early in the mining process. Information about aquifers in the overburden, aquifer recharge and discharge, hydraulic connection among aquifers, and the importance of the ground water resource is needed. Information about the geology of the mining area can be obtained from geologic maps, drilling information, testing of piezometric surface levels, and other geologic studies.

If water balances, dissolved solids balances, and the hydraulic properties of aquifers are understood, generally the ground water system is understood. Water level fluctuations indicate recharge and discharge activity in aquifers. Fluctuations can be measured by placing a recorder on a well to obtain water levels, which are then correlated with precipitation events.

The interchange between ground water and surface water should also be considered in conjunction with aquifer recharge and discharge. The hydraulic connection between streams and aquifers often occurs through the alluvium, since an alluvial aquifer is usually associated with a stream. Aquifer interaction with streams can sometimes be identified through measurements of the piezometric surface levels and the water table in relation to stream levels. If the piezometric surface and the water table tend to come together near the streams, an interaction is indicated, and stream elevation is controlling the piezometric surface level near the stream. Gains and losses in stream discharge can sometimes be measured, if differences are large enough. If the chemistry of the ground water is different from the chemistry of the stream water, monitoring water above and below the mine site for the chemical content can indicate any chemical changes, and, thus, can be used to estimate relative recharge and discharge.

Aquifers do not always behave independently and water may move from one to another. Such interchange should be identified because mining impacts on one aquifer could also affect others.

The degree of importance of ground water resources should be assessed according to present and potential uses of the aquifers. In cases where ground water quality is so bad that the water is not usable for anything, consideration of ground water resource should be different than where a ground water resource is either very important or a potentially important component of the water supply.

What impact does mining have on subsurface water?

If an aquifer supplying recharge to streams is disrupted by mining, the base flow contribution

to streams will be affected through changes in both the quality and supply of ground water to streams. Changes in ground water flow patterns and an altered water table or piezometric surface can also result from mining.

Discussion:

Changes in ground water quality. During mining, percolating water may come in contact with mineral surfaces, which could increase levels of dissolved solids, and/or trace elements in the ground water. Also, ground water quality can be altered by input of water percolating from mine pits, shafts, and tailings impoundments. Since the amount and quality of recharge to the ground water supply can be altered by mining, the ground water supply to streams may also be altered, which can affect the condition of fisheries.

Changes in flow patterns. The hydraulic conductivity and transmissivity of material backfilled into a disrupted aquifer will usually be different than the material that was there before the aquifer was disturbed, and changes in flow patterns should be expected to occur. This will produce two effects, both of which can be calculated. If the spoils have a higher hydraulic conductivity than the existing aquifer, there is a tendency to increase ground water flow through the spoils area. On the other hand, if the spoils have a lower hydraulic conductivity than the existing aquifer, there is a tendency for water to flow around the area.

Mining can also affect the recharge and storage capacity of an area. When impervious rock strata above an aquifer are shattered by mining, the resultant spoils can store more water and also act as a new recharge area.

Lowered water table or piezometric surface. By putting a pit or a shaft into an aquifer, a pressure sink can be created and the water table or piezometric surface that exists prior to mining can be lowered. The effects of this can be measured, further and further away from the mine site over time. For example, artesian wells away from the mine site and springs important to wildlife can begin to dry up.

Ground water mounds may form beneath settling and tailings ponds and increase the elevation of the piezometric surface in these areas. This may result in high subsurface ground water conditions, an increased downslope hydraulic gradient, and an increase in slumping activity.

SMALL DISCONTINUOUS GROUND WATER SYSTEMS IN MOUNTAINOUS AREAS

Ground water systems may develop in mine dumps located on steep slopes in mountainous

areas and contribute to stability problems. The ground water systems are not always perennial; rather, they often occur in the spring, during peak snowmelt periods. The main source of water for the system is usually snowmelt, although there may be a significant lateral contribution to the system from side slopes on the surrounding terrain. When ground water systems occur in the dumps, saturated hydraulic conductivities develop throughout the affected area of the fill. Stability problems usually occur within 4 or 5 ft of the mining surface and instability is usually apparent within 3 years of dump construction; however, the accuracy of prediction of dump instability is not high with our current level of knowledge.

How can mine dump instability caused by small discontinuous ground water systems in mountainous areas be avoided?

There are a number of engineering and reclamation techniques that can be used to avoid mine dump instability.

Discussion:

Perforated steel pipes or a French drain can be installed during dump construction as a passive drainage system to remove ground water from the slopes before slumping occurs; this has been done on the interstate highway system from Maine to Oregon. Passive drainage systems can also be installed on slopes with existing problems. Another construction technique, though it has economic limitations, is dump foundation construction, which includes compacting the bottom layers of fill. Also, surfacing mining dumps with materials that allow for minimum infiltration may minimize ground water problems, though this will increase surface runoff.

Tying mining waste dumps into native terrain, especially at the toe of the slope, should be done carefully. This is a common practice that often results in a mismatch of hydraulic conductivities between the spoils and the soil beneath. Sufficient passive drainage (French drains, for example) should be installed where such mismatches occur in order to insure effective drainage of the mine dump before it becomes mass unstable. Dumping spoil on vegetation can result in a slippage plane when the vegetation rots, so the dumping site should be scalped first. Planting woody, deep-rooting vegetation removes some of the excess water through transpiration and thus allows for more storage capacity during the recharge season. Furthermore, the deep roots tend to bind the surface or the upper layers of the spoil together, thereby promoting stability.

Chapter 4
SNOW MANAGEMENT

Chapter Organizer: Eugene Farmer

Major Contributors: Eugene Farmer, Robert S. Johnston, Ronald D. Tabler

Management of snow in mined areas becomes a topic of concern for the hydrologist in a number of situations. First, of course, is the consideration of whether or not snow distribution is a problem in the mining area. If it is, as determined through observation as well as measurement, then consideration must be given to how snow can affect the mining operation in terms of distribution, spoil/snow interaction, runoff, impacts on and benefits to reclamation, and access to the area. Major snow-related considerations are discussed further in this chapter.

How does the hydrologist determine whether snow distribution is a problem in the mining area?

The hydrologist should rely on the premining survey and inventory, as well as general knowledge of the area, in deciding whether snow is a problem.

Discussion:

Mining plans should include information on the winter climate: seasonal snowfall and precipitation water-equivalent, wind speed and direction, temperature (monthly means, maximums, and minimums), and the distribution of snow by wind. Snow drifting patterns should be documented by both aerial and ground photographs taken at monthly intervals throughout one or more winters. Snow profiles of major accumulation areas at time of maximum accumulation should also be included.

Wind direction prevailing during the drifting season (if any) can be determined from the aerial photographs, and from ground observations of drifting patterns, snow particle abrasion of posts and exposed rocks, and "hedging" of vegetation.

How will snow distribution affect mining operations?

While impacts are site-specific, effects will be elevation-related, leading to different problems on the plains than in mountainous mine sites.

Discussion:

Snow distribution patterns reflect the interaction of seasonal snowfall amounts, topography, vegetation, wind, and air temperatures. Snow distribution should be considered of major importance in areas where blowing and drifting snow are common features of the winter climate. Snowdrifts can block access roads and generally impede mining operations.

Another problem that must be considered is soil erosion generated by melt from drifted snow. Surface runoff from rapid melting of these drifts may result in rill and gully formation. Saturation of dumps, resulting in slumping or mass failure, may also occur. This is particularly true on mines located in mountainous terrain. Both of these occurrences may contribute to sediment loads in streams. Finally, irregular, old dump sites may increase snow retention, resulting in too much water being held within the waste materials.

Two possible solutions exist for these problems. First, in areas where snow drifting is determined to be a problem prior to mining, proper mine design may be effective in reducing snowdrift accumulation. Second, if the mine already exists and has not been designed to mitigate snowdrift problems, methods are available for manipulation of snow movement on-site.

What are the most effective methods of controlling snow deposition?

The most common methods of controlling

snow deposits are snow fences and other artificial barriers (fig. 5). Other techniques include manipulation of the terrain (shaping), and management of the surface roughness.

Discussion:

Properly designed snow fences can provide effective protection against snowdrifts, or they can be used to store large volumes of water to augment local water supplies for irrigation or other uses. (Figure 6 shows how to determine volume of water stored.) The keys to successful snow fence systems for preventing drifts include: (1) sufficient *capacity* to store the predicted seasonal snow transport; (2) the use of *tall* fences in preference to multiple rows of shorter structures; (3) proper *fence design*; (4) proper *placement* in relation to the protected area; (5) the use of *long* fences (greater than 30 times the fence height); and (6) *orientation* perpendicular to the prevailing wind.

Snow transport water-equivalent, q (in ft^3 of water per foot of fence length) can be estimated from

$$q = 5000\ P_r\ (1 - 0.14^{0.0001R})$$

where P_r is relocated precipitation (feet, water-equivalent) and R is the "fetch" or contributing distance (feet). This method is described in the reference by Tabler (1975a). For 50-percent porous fences on level terrain, the maximum water-equivalent capacity of a snow fence having height H is approximately $10H^2$. From these relationships, then, it is possible to determine the required fence height. Construction cost per unit volume of snow storage decreases with increasing fence height, so it is less expensive to build a single row of 12-ft-tall fence, for example, than 4 rows of 6-ft fence having equivalent capacity.

Proper fence design includes 50-percent porosity, a bottom-gap of 0.1H, and the use of horizontal slats having widths less than (approximately) 8 inches. A 15° inclination from verti-

Figure 5. Snow fence.

cal, downwind, also increases capacity by about 25 percent. Engineering drawings for effective snow fences are given in Tabler (1974).

The maximum length of the lee drift behind a full fence is 30H, so fences should be placed at least 30H upwind from the area to be protected.

Snow fences for protecting transplanted shrubs and augmenting soil water should be shorter, or more porous, than those used for drift prevention. Fences that are 2 ft tall, spaced 60 ft apart, will provide a relatively uniform snow cover on level terrain. On windward-facing slopes (greater than about 10 percent) or on ridge crests, however, spacing should be reduced by about half in order to achieve a uniform snow distribution. Fencing that is 4 ft high, having about 75-percent open area (porosity) will also result in a sufficiently shallow, uniform deposit, at least on level terrain. Again, spacing should be about 30H, or 120 ft for a 4-ft fence.

The most economical method of snow management for augmenting soil water, however, is through manipulation of surface roughness rather than the use of artificial barriers. In general, mined areas should be left with as rough a surface as possible, to provide numerous depressions for snow retention. Contoured furrows, ripped strips, terraces, and pits or gouges are all preferable to smoothly graded and harrowed surfaces; however, careful contouring of two-dimensional roughness features is essential to avoid gradients that might induce gully formation.

Benefits of rough surfaces include retention of rainfall as well as snow, reduced evaporation, protection against abrasion by wind-blown soil and snow particles, shading, and reduced wind and water erosion. Rough surfaces are gradually smoothed out by weathering processes over the course of the few years needed for successful establishment of vegetation.

Another possible method for controlling deposition of wind-transported snow is through appropriate shaping of the terrain. The method

Figure 6. Ideally, a snow fence is 50-percent porous; a simple equation—10 x H^2 (height of the fence)/lineal ft of fence—can be used to determine approximately the volume of water stored behind a snowfence.

described by Tabler (1975b) can be used to predict snow accumulation in various terrain configurations, allowing design of drift-free roads and shaping of terrain to optimize snow distribution to facilitate revegetation.

Additional Information:

For further information on snow fences, refer to:

Tabler, Ronald D. 1973. New snow fence design controls drifts, improves visibility, reduces road ice. Annu. Transp. Eng. Conf. (Colo. Univ., Denver, February 1973) Proc. 46:16-27.

Tabler, Ronald D. 1974. New engineering criteria for snow fence systems. Transportation Research Board (National Research Council) Trans. Res. Record 506:65-78.

Tabler, Ronald D. 1975a. Estimating the transport and evaporation of blowing snow. p. 85-104. *In*: Snow Manage. on Great Plains Symp. (Bismarck, N. Dak., July 1975) Proc. Great Plains Agric. Counc. Publ. 73, 186 p.

Montagne, John, J. T. McPartland, A. B. Saper and H. W. Townes. 1968. The nature and control of snow cornices on the Bridger Range, Southwestern Montana. USDA Forest Service, Misc. Report No. 14. Alta Avalanche Study Center, Wasatch National Forest.

For further information on terrain shaping, refer to:

Tabler, Ronald D. 1975b. Estimating the profile of snowdrifts in topographic catchments. Proc. West. Snow Conf. 43:87-97.

Packer, Paul E. 1971. Terrain and cover effects on snowmelt in a western white pine forest. Forest Science, Vol. 17, No. 1, March, pp. 125-134.

What impact does snow contaminated by mining have on water chemistry?

Snow contamination may occur hand-in-hand with acid mine drainage, when oxidation of sulfide minerals occurs. The symptom of this is that metallic concentrations and the mass flow of metals in streams increase during peak snowmelt periods.

Discussion:

Snow contamination occurs via two sources: (1) the incorporation of reactive dust within the snowpack itself; and (2) the capillary suction in the snow/ice matrix at the snow/ground interface.

In snowpacks 5-6 ft deep near high-altitude heavy-metal mines, as many as half a dozen layers of dust materials can be seen. When analyses are run on the contaminated material, it is found to consist primarily of sulfide minerals with a pH of between 2 and 3. This material does not contribute any acid load itself, because oxidation of sulfide minerals is a chemical reaction and is affected by the temperature surrounding the reaction. In a snowpack 32°F or colder, this reaction proceeds very slowly, and is not a source of acid production until the snowpack melts and the material is deposited on the surface. Then, during the summer warm period, the reaction occurs and sulfuric acid is produced. The amount of dust incorporated in the snowpack is variable and depends on what the source of the dust is and how it is measured. For example, in two mines, where the walls are very steep, deposition of as much as a ton of dust per acre over a winter is possible near the margins of the pit.

Regarding capillary suction, the snow/ice matrix acts like a sponge in picking up acid products from the surface of the soil. As snowmelt proceeds and the snowpack starts to bleed snowmelt water, the initial flush will have a metallic ion concentration up to 30 times greater than succeeding increments of snowmelt. The first increment acts as a concentrating mechanism. Thus, during periods of peak snowmelt runoff, a direct relationship exists between stream flow volumes and metallic ion concentrations. How far the ions are sucked up into the snowpack depends on the matrix at the snow/soil interface, but at one mine the height was as much as 15 cm.

How can snow contamination be prevented on mine sites?

Two measures are helpful: (1) minimizing dust production at the site as much as possible; and (2) reducing the acidity on the surface.

Discussion:

Opportunities for reducing dust production are limited at an open-pit site. One possible method, however, is to eliminate any dump faces that might be blown free of snow or become wind-scarred during the wintertime.

Revegetation appears to be the key to solving the problem of acidity reduction. The spoil material should be topsoiled and vegetation established so the sulfide particles cannot be moved, thereby reducing exposure of new surfaces and decreasing the opportunities for oxidation of these sulfide materials to produce acid.

Note:

The problems discussed in the section on snow contamination may be important at some sites. The most important principle, however, is that snowmelt water provides the excess water for flushing the products of oxidation and heavy metals that have accumulated in the spoil materials.

Chapter 5
ROADS

Chapter Organizer: Ed Burroughs

Major Contributor: Ed Burroughs

The hydrologist will provide input about the hydrologic impacts of mining roads during their design, construction, and maintenance. Even before construction gets underway, however, he should be aware of potential problems, and be able to advise on mitigating actions during his examination of the mining plan.

While the topics addressed in this chapter are particularly concerned with roads constructed for a mining operation, it should be remembered that many times mining roads are used for other forest operations—timber harvesting, for example. Therefore, the hydrologist can generally draw upon principles learned from other types of operations in solving mining-related road problems.

What is a mine road?

Mine roads may be quite large—as much as 60 ft or more in width—with a ditch and a berm. They are high-standard roads, are compacted and made of dense material in order to sustain traffic of 200 tons or more. In some cases, forest roads (those typically found in Forest Service operations) will be used for mining purposes.

Discussion:

Of concern to the hydrologist is the fact that since a large impermeable area is created by the road, water will run off rapidly during intense storms. Even the smaller roads found at some mine sites are still fairly impermeable, and thus, may have the same problem on a smaller scale. When water runs off at the berm, which is looser, an additional source of sediment is created.

What are the major hydrologic impacts of mine roads?

The major impact of roads on the surface water resource is concentration of runoff and resulting sediment yields. A minor effect of roads on the water resource is caused by fugitive dust settling on vegetation and soil adjacent to the stream channel where it can be washed into the stream by rainfall or snowmelt. Another minor impact is the damming effect of roads, which causes an impediment to subsurface flow under the roads.

Discussion:

In some mining situations, such as large coal operations in the Northern Great Plains, the total impact of roads may appear to be relatively minor compared to the impact of the entire mining operation. The impact, however, can still be significant, and must not be overlooked. In other mining areas, such as the Overthrust Belt from Utah to Canada, where intensive oil and gas exploration is occurring, the impact of the extensive network of access roads may be much greater, compared to the size of the rest of the operation.

Fugitive dust is basically an engineering problem, and while the hydrologist may not be called on to deal with it, he should nevertheless be aware of the consequences.

The damming effect of roads occurs when a fill is being constructed over slopes and shallow soil mantles. Water that would normally go over the bedrock under the road no longer can because of compaction of the material, which changes the hydraulic conductivity of the material under the road.

How much sediment will a road produce?

This question should be addressed in two parts: (1) sediment produced by road cuts and fills; and (2) sediment produced by the road surfaces and ditches.

Discussion:

Road cuts and fills. The hydrologist has a number of tools available for estimating the impacts of cuts and fills. One of the best is a report by the National Transportation Research Board (under the National Academy of Sciences), which uses the Universal Soil Loss Equation as a basis for estimating soil erosion from cuts and fills. The method takes into consideration rainfall intensity, rainfall energy, soil, slope length, and gradient in both a vegetated and unvegetated condition.

This information is best used to estimate the relative differences in treatment to stabilize road cuts and fills so that alternatives can be developed. For example, suppose two treatments, A and B, are under consideration. Treatment A would yield 200 lb/acre of soil loss; treatment B would yield 375 lb/acre of soil loss. In terms of accuracy, the relative estimated difference between the treatments is more accurate than the absolute estimate of the soil loss from either treatment. In other words, there is more confidence in the 175 lb/acre difference than in the estimation of sediment yield for either of the two treatments themselves.

When using the Universal Soil Loss Equation, the hydrologist should keep in mind that reservations as to its complete accuracy have been expressed, for four major reasons. These are: (1) The Universal Soil Loss Equation does not provide any satisfactory way to handle the snowmelt water component, and it is estimated that as much as two-thirds to three-fourths of mine-dump erosion in Western mountainous terrain occurs as a result of snowmelt. (2) Sufficient testing of K factor values of mine spoils has not yet been done to merit assurance of the accuracy of the values, so these should be used cautiously. (3) The equation is not designed to handle gully erosion; rather, it is designed to handle only sheet and rill erosion flows. (4) The Universal Soil Loss Equation is designed to be an average annual estimate, not an estimator related to a single storm event.

Road surfaces and ditches. While a predictive model exists for estimating soil erosion from road surfaces and ditches, there is not yet a reliable method for tying the model to actual events. The predictive model is called the Road Sediment Model (ROSED), and was developed by the USDA Forest Service Rocky Mountain Forest and Range Experiment Station at Ft. Collins, Colorado. The model is designed to estimate the runoff hydrograph based on given rainfall conditions and soils information pertaining to infiltration. It will estimate runoff and sediment by time increments so that a sediment concentration curve can be built. The model is also designed to predict sediment yield by size classes.

It should be noted that, while the theoretical portions of the model have been developed, at this time, there has not yet been a reliable confirmation of the model's accuracy through testing it against actual storm events. Data collection and analysis, however, are proceeding, and the results of these endeavors should be available in 1980. Therefore, a discussion of the use of ROSED is included here.

In order to use this model, the hydrologist should find a road in the area similar to the planned road. Measurements should be taken for such factors as densities, particle size, and gradation to develop an estimate of what the infiltration will be. In addition, available loose soil on the road surface must be estimated, and again, an analogous road can be used for doing this. Surface roughness must also be estimated, and according to the ROSED, roughness has two major components: grain resistance to flow, which is particle-size graduation of surface material, and form resistance to flow, which is caused by the rock surfacing that is put on top of the material. Presently, techniques are being developed for the hydrologist to use in estimating form and grain roughness for a planned road.

No matter what prediction model the hydrologist is using, he will have to determine the most significant erosion-generating climatic event. This depends on area of the country, of course. For example, in the Southwest, the intense thunderstorms will probably generate the most significant amount of erosion. At low-to-moderate elevations, the rain-on-snow event may be most significant, while the intense snowmelt season at high elevations will generate the most erosion.

What can be done to mitigate impacts caused by roads?

A number of techniques exist, including control of culvert discharge and installing sediment

ponds below large fills or points where ditch discharge is dumped.

Discussion:

On the smaller forest roads, refer to "Guides for Controlling Sediment From Secondary Logging Roads" (see Additional Information) on using obstructions to cause sediment deposition below culvert outfalls. On larger roads, the problem is more complex because the level of knowledge is still slight. It is known, however, that in addition to controlling culvert discharge on these roads, road cuts and fills can be revegetated, and downspouts can be installed below culverts.

On wide roads, sediment ponds below large fills or points where road ditch discharge is dumped can be helpful. A short course offered by the University of Kentucky at Lexington pulls together available technology for design of sediment ponds in terms of detention time, spillway design, and so forth, which may be of value to the hydrologist. A similar course is offered at Oregon State University.

Since sediment-carrying water is commonly diverted off mining roads and into streams, consideration should be given to finding ways of keeping such sediment-laden water out of streams. This might be accomplished by breaking up the drainage off roads and by installing more frequent drainage points so that the volumes of water coming off at any one point are not great enough to flow into streams. Planting vegetation at runoff points can help to dissipate the flow; however, the hydrologist must also consider the timing and the quality of the sediment entering stream channels where fisheries exist. In general, while the sediment needs of fish are site-specific, during periods of high water flow, fisheries can tolerate more sediment than during low flows. For example, during the summer, a low-flow period, when sediment comes off a road system into a fishery, there may not be sufficient power in the streams to move the sediment that settles on top of spawning areas or drain areas. Thus, although it is generally desirable to keep as much sediment as possible out of channels, this goal must be balanced against the needs of the fishery for sediment. The hydrologist should be involved in review of the operating plan to insure that standards for sediment control at fisheries are set properly to accommodate these needs.

When should the hydrologist be concerned with mass erosion problems caused by roads?

In areas where heavy snowpacks occur, where very intense snowmelt rates occur, where ground water is accumulated, or where steep slopes and shallow soils exist, stability problems become significant. The hydrologist will be called on to walk proposed road locations to help identify potential stability problems.

Discussion:

In areas where mass slope failure is common, the hydrologist must become proficient at identifying those portions of the watershed that may become unstable as a result of road-building. The key is to learn to identify areas of the terrain where ground water concentrations can occur. These may be in ephemeral channels next to a ridge; in small bowl-shaped depressions (headwalls); in very steep slopes, in very shallow soils—in other words, points where ground water can accumulate either as a result of rainfall or snowmelt or both.

A model has been developed for the Oregon Coast ranges to predict ground water rise in feet for storms of various given intensities. While this model has not yet been widely-tested, it does offer a method for developing regional ground water prediction equations for other areas.

Instability indicators can be found on the ground, as well as by consulting topographic maps, geologic maps, and area photographs. A source of information on slope stability is a publication put out by the Oregon Bureau of Land Management "Slope Stability and Road Construction." Once unstable areas are identified, experts such as materials engineers or engineering geologists can be called upon to make a detailed examination on the ground.

Additional Information:

For a summary of the National Transportation Research Board's report, refer to: "Highway Erosion Control System: An Evaluation Based on the Universal Soil Loss Equation," by Gene Farmer and Joel Fletcher. Reprint from Soil Erosion Prediction and Control, Soil Conservation Society of America, p 12-21. 1976.

For more information on the Road Sediment Model, refer to: "Formulation of Road Sediment Model," by D. B. Simons, R. M. Li, and I. Y. Shiao. Publication No. CER 76-77DBS-RML-LYS50. Colorado State University, Civil Engineering Dep., Engineering Research Center, Ft. Collins, Colo. 80523.

For more information on using obstructions in sediment control, refer to: "Guides for Controlling Sediment From Secondary Logging Roads," by P. E. Packer and G. W. Christensen, Intermountain Forest and Range Experiment Station, Ogden, Utah, and Northern Region, Missoula, Mont. 1967.

For more information on the University of Kentucky's short courses on impoundments, contact: Dr. B. J. Banfield, Dep. of Agricultural Engineering, University of Kentucky, Lexington, Ky. 40506.

For more information on slope stability, refer to: "Slope Stability in Road Construction," U.S. Dep. of the Interior, Bureau of Land Management, Oregon State Office, P. O. Box 2965, Portland, Ore. 97208.

"Landslide Hazards Related to Land Use Planning in the Teton National Forest, Northwest Wyoming," by Robert G. Bailey, USDA For. Serv. Intermountain Region. 1971.

Chapter 6
EFFECTS OF RECLAMATION ON SURFACE WATER

Chapter Organizer: Paul Packer

Major Contributors: Robert S. Johnston, Paul Packer

In chapter 2, hydrologic processes and components that are affected by mining were discussed. This chapter looks at these factors again, this time in light of management steps that can be taken to mitigate the effects of surface mining disturbance on surface hydrologic behavior. Within limits, the hydrologic regime of an area disturbed by surface mining can be modified by practices that alter hydrologic transmission rates and/or storage capacities. These practices include management of topsoiling, surface configuration, subsoil layering, mulching, and vegetation, and are discussed in this chapter.

In general, what is involved in carrying out reclamation to maintain or improve surface water?

Reclamation can be either preventive or corrective. Preventive reclamation is predictive—that is, hydrologic disturbance as a result of mining is predicted according to known principles, and solutions, both biological and engineering, are specified in the planning stage. Corrective reclamation takes place as unpredictable events affecting the hydrologic system occur throughout mining.

Discussion:

Anticipated problems associated with surface water and mining should be considered in the mining plan. Based on similar mining situations, both the problems and likely successful solutions to those problems can be included in the plan. Predictable problems include channel erosion, stream bank and channel instability, degradation of streams, aquatic community problems, and water quality, in terms of both sediment and chemical composition.

Catastrophic events, however, which will require corrective reclamation, are usually accidental or are acts of nature and cannot be predicted. When confronted with such events, the hydrologist, working with other members of the ID team and the mining company, will be in a position of recommending mitigating measures. Thus, his knowledge of the hydrology of the site, as well as general hydrologic principles, should enable him to suggest alternatives for dealing with both the expected and unexpected problems.

Specific techniques for carrying out reclamation to protect surface water follow.

What effects do topsoiling or surfacing have on surface water reclamation?

There are two major purposes for topsoiling a spoil area: (1) to provide an acceptable growth medium for plants; and (2) to provide better infiltration and less surface runoff of water—and, hence, less erosion.

Discussion:

Adding topsoil is important in heavy-metal mining areas in the West where acid drainage is encountered with surface mining. Wind and water erosion constantly renew the supply of pyritic material for oxidation and hydrolyzation to form sulfuric acid. Placement of a layer of topsoil at least 30 cm thick is effective in reducing the acid formation rate by preventing further erosion of the pyritic surfaces, by reducing the oxygen supply available to the pyrite, and by reducing the amount of water moving through the pyritic layers. Where highly sodic spoils occur, surfacing with more neutral materials usually benefits the surface runoff quality. In general, then, when a good growth medium can be placed on top of the spoil in acid- or sodic-producing areas, better runoff quality can be achieved. In spoil materials that do not contain toxic materials, surfacing with topsoil is still highly desirable in order to pro-

vide improved infiltration and water-storage capacity in the spoils, thus helping to reduce overland flow and its attendant erosion hazards and promote revegetation efforts.

Exception: On steep slopes, spoil materials that are higher in rock content tend to form rock pavements and prevent further erosion. Topsoils that are lower in rock content do not form pavements as readily and may erode more extensively.

How can surface configuration be managed to improve the hydrologic characteristics of mining spoils?

Both the macro- and micro-topography of surface-mined areas can be modified to increase depression storage, reduce slope length, and eliminate ponding of waters. All are desirable.

Discussion:

Increasing depression storage increases infiltration and decreases direct surface runoff and, thus, erosion. Reducing slope length greatly decreases the concentration of surface runoff; both slope gradient and slope length of many mine spoil areas can be reduced to the point that almost all the water that accumulates from storms is retained. Changes in surface configuration can also affect redistribution of snow in areas where drifting snow creates water stresses on mine spoils, or where retaining snow might be desirable and useful in providing water for vegetation.

In humid areas, which, in the West, are the mountainous snowpack areas, surface configurations that conserve much of the water may cause other problems more serious than those caused by the runoff and erosion that result if the water is only partially contained. When large amounts of water are contained on the slopes, either by high infiltration capacities or in contour trenches, the danger of mass landslides can be increased. This is particularly true in areas where the normal hillside slopes are steeper than 30 percent. Such mass instability can aggravate surface instability, causing increased erosion and deterioration of water quality through sedimentation.

Terracing systems on steep spoil dumps in humid areas help to prevent severe rill and gully erosion by reducing the effective slope length. The water discharge from the terrace channels must be conveyed off of the slopes by means of stabilized outlets or subsurface drains. The chief disadvantage of such terrace systems occurs where deep winter snowpacks develop, because during the spring, when alternate freezing and thawing take place, ice tends to develop in terraces. In this case, terraces may not drain effectively and water either percolates back into the spoils, aggravating internal water problems, or overtops the terraces, producing serious rill and gully erosion.

In arid regions, terracing at strategic locations can be advantageous, serving both to discourage runoff concentrations where it is not desirable, and to concentrate water into control areas where it can be used to maintain plant growth. In other words, surface configuration can be used to harvest water for enhancing revegetation.

How can subsoil layering be used to improve the hydrologic characteristics of mining spoils?

During spoil-dump construction and backfilling after surface mining, materials can be sequenced in layers to modify the hydrologic behavior of the areas involved.

Discussion:

When surface layers are coarse and have a low water-holding capacity, this capacity can be increased to aid revegetation by placing a compacted or restricting layer just below the plant root zone. Similarly, compacted layers that restrict water flow can be placed above high-sulfide materials, to restrict oxidation and hydrolyzation of the sulfides. Effective use of subsoil layering to achieve specific hydrologic objectives requires complete knowledge of the infiltration and hydraulic conductivity characteristics and behavior of different overburden materials. Some knowledge of the chemical composition of these layers is also essential.

How can mulching be used to alter the surface hydrology of mined land?

Mulches can be used to: reduce evaporation, allowing water to remain near the spoils surface for a longer time, thus enhancing the opportunity for seedling survival during revegetation; intercept raindrops, thus protecting surfaces from puddling and splashing; reduce the velocity

of surface runoff, and thus surface erosion, by increasing the infiltration opportunity time on the spoils; insulate soil surface to prevent excessive high surface temperature; and prevent soil freezing.

Discussion:

Reduction of heat energy on the soil surface from solar radiation can be positive or negative. On north-facing slopes, such reduction can cause soil to remain cold during the spring, thus delaying or reducing seedling germination. However, heat reduction can sometimes enhance the growth of seedlings by preventing soil from drying out. Differences in the temperatures of soils caused by differences in materials color can also be minimized by use of mulch.

In some instances, mulches can increase the total infiltration capacity sufficiently to enhance the leaching of salts out of the surface spoils materials, which can prepare the surface for better early plant growth than is possible without mulch. This is especially true on oil shale, and may be true on some highly sodic coal areas.

The use of mulches for erosion control on mine spoils during the time it takes to establish a plant cover is most effective where spoil dump slopes are in excess of about 30 percent. As slope steepness decreases below 30 percent the value of mulches strictly for erosion control drops off rapidly in relation to their cost.

How does vegetation affect the surface hydrology of reclaimed mine lands?

The amount and kind of vegetation cover protecting spoils is an important determinant of the infiltration, surface runoff, and erosion behavior of mined lands, as well as hydraulic resistance of the surface to overland flow.

Discussion:

In selecting species to plant on surface-mined areas, an important factor to consider is the ability of the plants to grow under the local conditions. The next consideration should be the effectiveness of the vegetation for water control. Control can usually be achieved more quickly with grass or mixed plantings than with shrubs and trees alone.

The rooting depth of vegetation has a significant effect on the surface hydrology in arid and semi-arid climates where shallow-rooted vegetation is often subjected to water stress. Overland flow will be greatly decreased and total runoff will be somewhat decreased if the watershed is covered with deep-rooted vegetation than if covered with shallow-rooted species. Most important, however, is the plant basal area and litter density for control of overland flow. This becomes especially important where surface-mined areas to be revegetated comprise substantial proportions of water-yielding watersheds.

How can the hydrologic consequences of mining reclamation be evaluated?

Very little research has been done on the hydrologic effects of surface-mine disturbance and reclamation. The research that has been done has, to some extent, developed ranking criteria for some limited aspects of hydrology, particularly surface hydrology. Studies, however, have not yet been designed to produce information that can be integrated into a quantitative prediction model useful in designing management procedures for specifying hydrologic goals on mined land.

Discussion:

The evaluation of the hydrologic consequences of surface mining and reclamation activities on surface-mined lands requires procedures that quantitatively predict a flow or storage component of a hydrologic cycle for various alternative practices. Quantitative evaluations require the development of models of water, chemical, and sediment transport on disturbed and rehabilitated areas; other models must represent descriptions of how water, chemicals, and sediment move under alternative management systems or practices. These models must observe the basic physical principles of hydrology and also incorporate the principles of chemistry, biology, and plant science needed to describe a biological system. Out of necessity, these models also must include a number of empirical laws or considerations and require extensive field data.

What assistance is available to the hydrologist involved in surface water reclamation?

The hydraulic engineer, forest engineer, and regional hydrologist, as well as regional engineers, consultants, and university specialists, can assist with surface water reclamation.

Discussion:

While the hydraulic engineer will not necessarily have specific knowledge of soil/plant interaction, his expertise may be more valuable to the hydrologist during this stage of mining than that of other types of engineers. The hydrologist can rely on the hydraulic engineer, in addition to Forest Service specialists and research personnel, consultants, and university specialists, for information about innovative reclamation techniques, both tested and untested, in a specific area.

Chapter 7
SUBSURFACE WATER MANAGEMENT AND TREATMENT

Chapter Organizer: Eugene Farmer

Major Contributors: Eugene Farmer, David B. McWhorter

In general, very little can be done during the reclamation phase of mining regarding ground water. It should, however, be remembered throughout the mining process—including reclamation—that what is done regarding surface water directly affects subsurface water, though there may be a time lag involved in the manifestation of the effects. As emphasized previously, the hydrologist must be aware of potential impacts on subsurface water before mining actually gets underway. Then, during mining reclamation, his major role is to monitor certain factors/activities that were identified during the planning phase as potential problems; be aware of possible problems that might occur as a result of general reclamation activities; and advise the mining company of steps it can take to mitigate harmful impacts. This chapter summarizes subsurface water treatment concerns the hydrologist should be aware of, and possibly have to make recommendations on.

What aspects of subsurface water management and treatment should the hydrologist be concerned with during reclamation?

Before and during reclamation, the hydrologist may be involved in predicting and estimating what the long-term ground water chemistry will be; permanent changes in aquifer flow patterns; recovery time and equilibrium levels of the piezometric surface and water table in mined areas where water has been withdrawn from the pit; and whether permanent changes may occur in the water balance. He will also be concerned with mine dumps and tailings impoundments as they affect subsurface water, and monitoring of these effects of the system (see chapters 8, 9, and 10).

Discussion:

In general, the hydrologist should, on a site-specific basis, take actions before the reclamation phase to protect certain valuable subsurface water resources. For example, the hydrologist may determine that mining will disrupt an aquifer that is the only good source of water for farming in the area. In this case, he should make recommendations to prevent deterioration of the aquifer or to guarantee its restoration. Possible recommendations he could make include installing a cutoff wall of clay or grout, or compaction of backfill to prevent destruction of the aquifer, or reconstruction of the aquifer through selective spoils placement.

The key word for the hydrologist to keep in mind in dealing with subsurface water considerations during reclamation is "site-specific." For example, it is very difficult to predict long-term changes in ground water chemistry that may result from mining, since no standard methodology exists for making such predictions. Thus, the hydrologist must apply what he knows about the site itself in predicting changes as accurately as possible, and recommending mitigating measures, if they are necessary.

Permanent changes in the flow patterns in aquifers become significant on a site-specific basis, as determined by the end-use, as well as the original quality, of the aquifer. It is assumed that some permanent changes in the water balance will result from mining activity, if the system is reasonably large. The relative magnitude of the system determines whether these changes will negatively impact the planned end-use of the area. If so, then measures to restore the balance, insofar as possible, must be recom-

mended by the hydrologist early in mining activity.

What problems associated with small discontinuous ground water systems in mountainous terrains can be managed during reclamation?

The major problems with these systems occur when the top few feet of spoil material slide off of rehabilitated areas. During reclamation, installation of drainage systems can help alleviate this problem.

Discussion:

Ideally, the development of these systems and the problems associated with them can be anticipated, and preventive steps taken early in the mining process. Passive drainage systems (those that require no maintenance), can be installed as the waste dumps are being rehabilitated. In addition, materials allowing for proper infiltration can be used to surface mine dumps; and snow accumulation on the mining area can be discouraged to reduce snowmelt, and thus infiltration.

Additional Information:

On design and spacing of drainage systems, refer to: "Analysis of Parallel Drains for Highway Cut-Slope Stabilization," by Rodney Prellwitz, Geotechnical Engineer, USDA For. Serv., Region I, Missoula, Mont.

For further information on ground water, refer to the EPA series of publications "Monitoring Groundwater Quality," by Todd, Tinlin, Schmidt, and Everett, EPA-600/4-79-019, 026,036.

Chapter 8
ACID MINE DRAINAGE

Chapter Organizer: Dale Ralston

Major Contributors: Eugene Farmer, Dale Ralston

During mining, ground and surface water flow systems may be modified or created that allow for acid production caused by an increased availability of water and oxygen to acid-producing mineral surfaces. Reclamation, then, involves controlling and/or modifying these flow systems.

In any mining situation, acid production is related to the amount of exposed surfaces of acid-bearing rock, occurring primarily in the few top centimeters of the surface exposed to oxygen or oxidizing compounds. Then, acid is transported by weeping or flushing of oxidized metal salts in the mine. (Weeping occurs underground as a result of constant dripping of poor quality water. Flushing—the biggest problem in acid mine drainage—occurs when water flows through the mine, taking with it the acid salts formed underground, then drains into surface or subsurface water systems.)

In abandoned or existing mines, acid mine drainage problems cannot be entirely solved, but they may be reduced by as much as 80 percent with proper management. Acid drainage that does reach streams can be treated through existing technology; the major limitation is cost.

In new and operating mines, preplanning can effectively limit acid mine drainage problems throughout the mining process. The costs of acid mine drainage control and specific techniques that can be used to limit acid production should be considered early in the mining process. Successfully limiting acid production will require the hydrologist's input throughout the entire life-cycle of the mine; historically, however, this has not been done.

What factors are associated with the occurrence of acid mine drainage?

For acid mine drainage to occur, iron sulfide (generally pyrite), oxygen, moisture in the mine atmosphere, other heavy metals, available water for recharge, and the physical characteristics of the mine itself must interact to produce acid and then allow it to drain from the mine.

Discussion:

These variables are the same for both surface and underground mining, and as long as they are present, there will be acid mine drainage (fig. 7). Elimination of any of the variables will eliminate acid production.

Generally, moisture in the mine atmosphere and the presence of iron sulfide and other heavy metals are uncontrollable factors and govern the production of acid in the mine. Following mining, residual iron sulfide and other heavy metals are generally still present, so accordingly their effectiveness for producing acid remains. Water in mines is difficult or impossible to eliminate; in deeper mines there is generally 100-percent humidity.

The amount of oxygen can be severely limited by flooding the acid-producing area of the mine; limiting oxygen by sealing the mine alone is generally unsuccessful.

Available water for recharge and the physical characteristics of the mine *are* controllable and govern the recharge or flushing effect of water. Without water for transport, the production of acid in mines will not impact areas surrounding the mine.

What data are needed for identification of acid mine drainage problems?

In order to identify acid mine drainage problems, the hydrologist must have data collected over time on: the amount and quality of discharge from portals; the spatial variations of

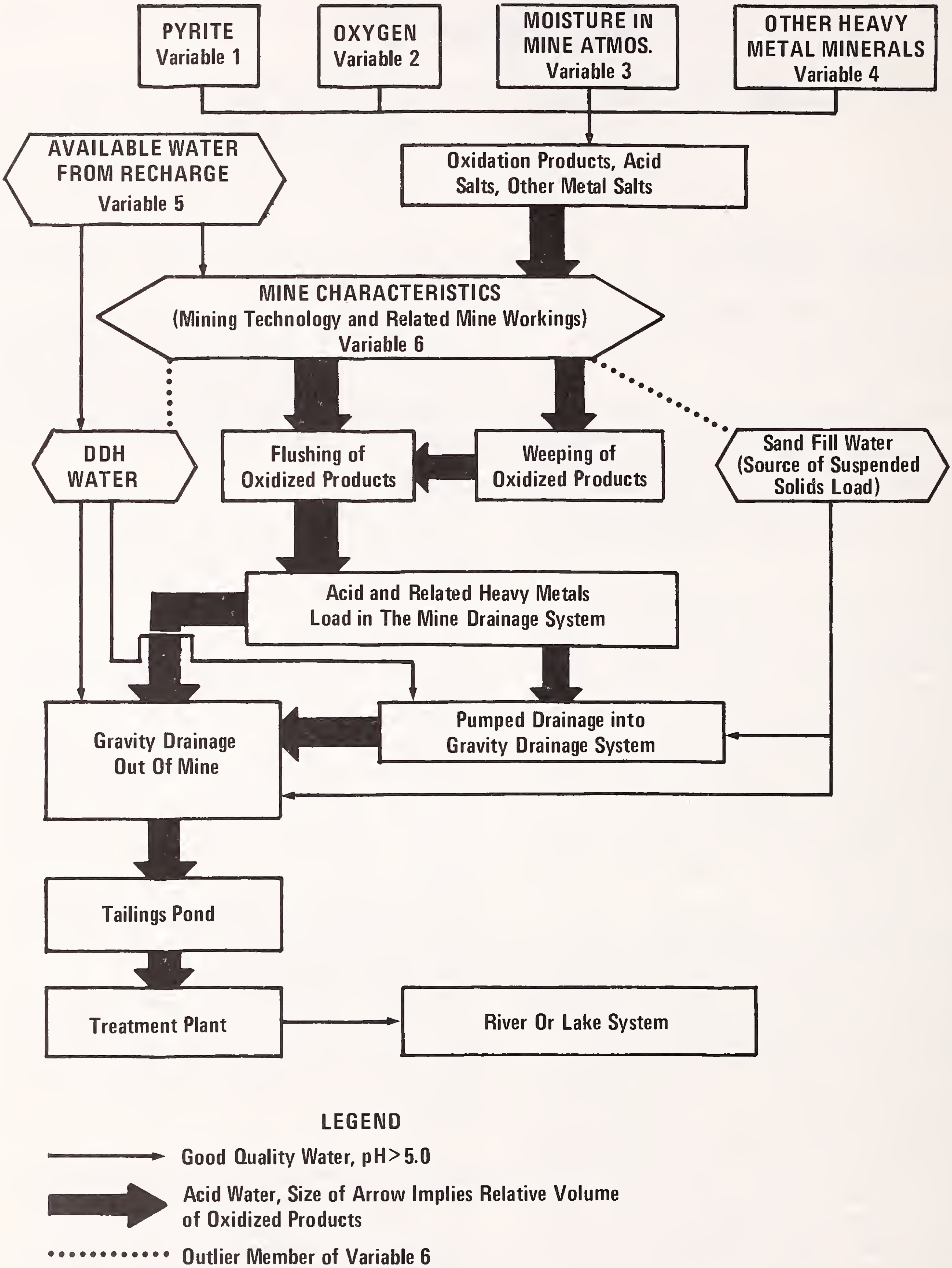

Figure 7. Variables in production of acid mine drainage. (Idaho Bureau of Mines and Geology, Moscow).

water quality and discharge underground; characteristics of the underground workings of the mine; the mineralogy of the mine; and possible sources of acid-drainage—the mine, waste dumps, other mines close by.

Discussion:

The most extensive data collection period should be during spring runoff.

Discharge from portals and underground should be described over one hydrologic cycle, so that variations can be identified.

Underground characteristics of the mine, the number of levels, number and location of raises to the surface, vents, stope areas where ore has been removed, waste deposits, surface waste deposits, and near-surface features (caved areas and increased vertical hydraulic conductivity) should be identified. Mining companies generally have this information, as well as information about the mineralogy of the site.

The source of the acid drainage should be carefully identified through testing of discharge from various mines, waste piles, and so forth, monitored over time.

How can acid mine drainage problems be classified?

Acid mine drainage problems can be classified according to their characteristics, and fall into four categories: (1) a mine with direct surface recharge and major acid production; (2) a mine with direct surface recharge and minor acid production; (3) mine drainage occurring from intercepted premining ground water flow systems with major acid production; and (4) mine drainage occurring from intercepted premining ground water flow systems without major acid production.

Discussion:

A mine with direct surface recharge and major acid production can be identified by mine drainage hydrographs indicating peak acid content coincident or nearly coincident with runoff or snowmelt events, and poor water quality that varies throughout the year. Lower concentrations of acid in mine drainage will occur during the fall and winter; the highest concentration will occur during peak flow discharge; the lowest concentration will occur immediately after the peak runoff event; and high concentrations occurring after peak flow will gradually decrease during the summer.

A mine with direct surface recharge and minor acid production will be characterized by mine drainage hydrographs with peak acid content coincident or nearly coincident with runoff or snowmelt events, and water quality that varies as described above except that the concentrations of metals vary from low to very low.

Mine drainage that may occur from intercepted premining ground water flow systems with major acid production is characterized by mine drainage hydrographs that are subdued and lagged replicas of local runoff, and water quality that varies directly with flow—for example, higher acid concentrations will occur with higher flow.

Mine drainage that may occur from intercepted premining ground water flow systems without major acid production is characterized by mine drainage hydrographs as described above, and water quality that varies with flow, but acid concentrations are low to very low.

What techniques can be used to solve acid mine drainage problems in abandoned or existing mines?

Three basic techniques are available; these are to: (1) reduce discharge and improve water quality; (2) maintain discharge and improve water quality; and (3) reduce discharge but not improve water quality. The techniques used to solve an acid mine discharge problem will depend on the specific problem being treated.

Discussion:

Reduction of mine discharge can be accomplished by reducing direct water recharge into mine workings and by reducing drainage into the mine from intercepted ground water flow systems (fig. 8).

To reduce direct recharge into mine workings, points or zones of water entry into the mine must be identified (stopes near the surface, raises or vents, caving areas, and open pit areas). Then, water movement into the mine areas must be reduced by: (1) constructing diversion structures to prevent overland flow from entering mine workings; (2) sealing raises and vents down to solid rock to limit shallow ground water movement into the mine; (3) regrading where possible to eliminate depressions caused by

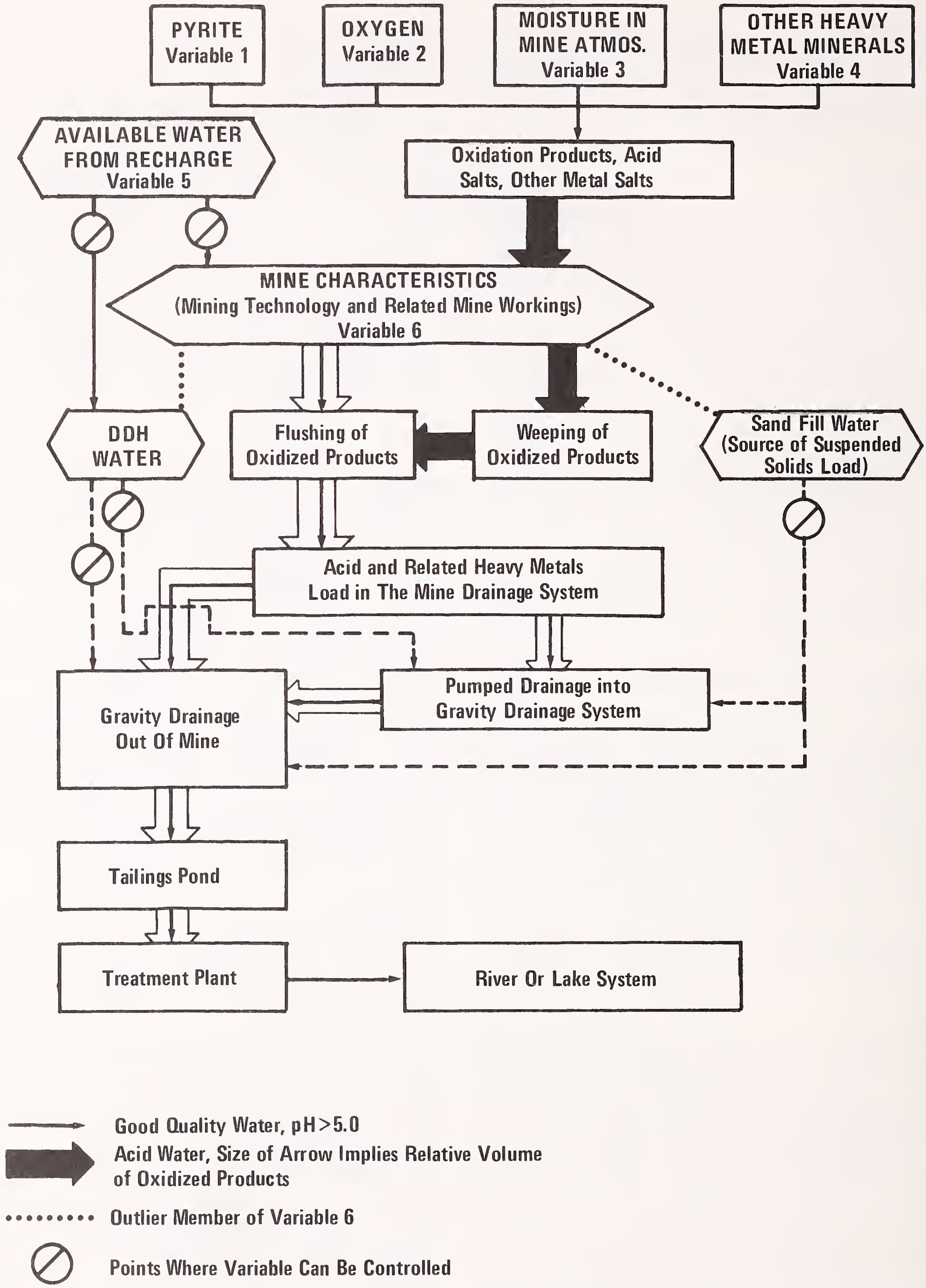

Figure 8. The effect on acid production by controlling variables 5 and 6 (Idaho Bureau of Mines and Geology, Moscow).

block caving and open pit ore removal; and (4) constructing sealed channels for streams where mining features underlie the streambeds at shallow depths.

To reduce drainage into the mine from intercepted ground water flow systems, points or zones of water entry into the mine must be identified. These include diamond drill holes, and stopes and drifts that intercept flow in fracture zones and fault fractures. Then, water movement into the mine workings must be reduced by: (1) sealing or plugging all flowing diamond drill holes; and (2) sealing any local stope or drift areas that produce considerable water. Fault fractures may be grouted to seal them.

Methods of improving the quality of mine drainage water include diverting water movement around high acid-producing areas in the mine and limiting the production of acid salts.

Regarding diversion of water movement around acid-producing areas in the mine, first, areas of acid-producing ore or waste rock must be identified. Next, paths of water movement in and near the acid-producing areas must be identified, and then water must be diverted around the acid-producing areas to allow a minimum flushing effect.

Regarding limiting the production of acid salts, oxygen can be eliminated from the mine atmosphere through sealing and/or flooding, or water can be neutralized near the acid-producing areas. To eliminate oxygen from the mine atmosphere, all mine openings or all openings to a given area must be sealed. This will not generally eliminate all oxygen from the mine atmosphere if the host rock is fractured. After sealing lower openings to the mine, the acid-producing area of the mine can be flooded. To neutralize water near the acid-producing areas, the feasibility of this alternative depends on the magnitude of the problem and the characteristics of the underground workings. This may be an alternative that requires renewal after a relatively short period of time.

Alleviation of a mine drainage problem often involves using a combination of several of the techniques mentioned. For example, in a given situation, all identifiable surface recharge to the mine may be minimized; all flowing drill holes may be plugged and high water-producing areas may be sealed off where possible; water around acid-producing areas in the underground working may be diverted to minimize the flushing effect; as much of the mine as possible (without creating many small seep areas) may be flooded; and all remaining discharge may be collected to minimize the number of mine drainage discharge points, a step that eases the cost of discharge treatment.

What other acid mine drainage problems may occur on existing or abandoned mines?

Additional problems connected with solving acid drainage problems on existing or abandoned mines include cost considerations and who has the legal authority and responsibility to deal with the problems.

Discussion:

Regarding costs, acid drainage problems on existing and abandoned mines are very expensive to correct, and money is not available to the Forest Service in most places for solving the problems. Some money, however, may now be available in States with coal; these States can use 50 percent of the money allocated under the Surface Mining Control and Reclamation Act of 1977 (P. L. 95-87, U.S. Code 30-USC 1201) to correct non-coal mine problems after the abandoned coal mines are reclaimed.

Regarding legal authority and responsibility to deal with acid drainage problems, most of the existing problems are on patented lands, so the Forest Service cannot work with the problems; also many of the mines are under court suits or court orders, so no one has the authority to do anything about them. Also, it has not yet been determined who is responsible for correcting problems with abandoned mines or who is legally responsible for pollutant sources, including acid drainage, coming off the land these mines are on.

How can acid drainage problems in new mines be minimized?

It is possible to predict acid drainage problems prior to mining, when an adequate data base is available. The data should include information on the mineralogy, hydrology, and physical characteristics of the mine. Then, when it is known that acid drainage will occur, a controlled environment—one minimizing acid production—can be constructed.

Discussion:

Such a controlled environment would limit the number of transport mechanisms for the acid. In other words, water should exit from the mine as a single treatable discharge. Limiting transport mechanisms is easier underground (where recharge is controllable) than in an open pit, so a company facing the costs of acid drainage control may decide to mine underground based on this consideration. In addition, waste piles for new mines should be located where they can be hydrologically isolated; that is, the surface beneath the wastes can be sealed and the surface of the waste pile can be revegetated. Also, during mining, topsoil and subsoil material should be stockpiled and used later to cap waste piles and other areas after mining is complete.

How can acid drainage from waste materials on the surface be controlled?

Acid drainage from waste piles at abandoned or existing mines can be controlled by surfacing, if acid problems are caused by water leaching down through the wastes and transporting acid. At new mines, acid drainage problems from waste piles can be effectively reduced by putting the wastes in a hydrologically isolated area.

Discussion:

On new, existing, and abandoned mine waste piles, surfacing with at least a foot of innocuous material, then establishing as heavy a stand of vegetation as possible on a layer of topsoil or subsoil, can effectively reduce the oxidation potential of acid-producing materials. According to the Environmental Protection Agency experiments that produced this information, 1 ft of the innocuous surfacing material was sufficient to reduce oxidation. Where possible, surfacing beneath waste piles, as well as on top, helps to control acid that may reach streams through deep seepage.

Exception: There are indications on some sites that acids and heavy metals in waste piles move upward and eliminate the vegetative cover that has been established. In some cases, the vegetative cover deteriorated more year by year. Specific hydrologic information about the movement of the acid in waste piles and about where acid production occurs in waste piles is lacking at this time.

What specific knowledge gaps exist regarding acid mine drainage?

(1) The effects of micro-climatic events on continuous low levels of acid production and its resulting effects on streams and fisheries are not known.

(2) Methods of tailings pond management, design, and location that can best control or minimize acid mine drainage problems are not known.

(3) The chemistry of acid production from pyrites is not entirely understood; in Eastern coal mines it is known that the nature of the pyrites has a tremendous effect on the severity of acid mine drainage problems, but the extent to which this is applicable in the West is not known.

(4) More information is needed on the general hydrology of acid mine drainage and the role of revegetation and topsoiling in minimizing the problem of waste piles.

(5) More information is needed about the translocation mechanisms of heavy metal salts to live stream channels.

(6) More information is needed about the natural recovery of streams after they have been damaged by acid drainage. Information on this is very limited, and while there have been a few cases where streams have been left alone with little restoration effort and they have partially recovered over time (Rock Creek in Montana, for example), information is not available for making decisions about how to best treat streams for recovery once acid drainage into them is halted.

Discussion:

These knowledge gaps pertain to existing, abandoned, and new mines. While these gaps do not deter efforts to prevent and/or control acid mine drainage, they do indicate that further work needs to be done in this arena.

Additional Information:

For more information about acid mine drainage in high elevations, refer to "Acid Mine Rehabilitation Problems at High Elevations," by Robert S. Johnston, Ray W. Brown, and Jack Cravens, USDA For. Serv., reprinted from the Watershed Management Symposium held by the ASCE Irrigation and Drainage Division, Logan, Utah. August 11-13, 1975.

Figs. 7 and 8 originally appeared in: Trexler, Bryson D., Jr., Dale R. Ralston, Dennis R. Reece, Roy E. Williams, Sources and Causes of Acid Mine Drainage. Dec. 1975. Idaho Bur. of Mines and Geology, Moscow. Pamphlet No. 165.

Chapter 9
IMPOUNDMENTS

Chapter Organizer: Grant Davis

Major Contributor: Clifford Hawkes

During review of the mining plan, the hydrologist will be faced with a number of considerations regarding impoundment of water on the mining site. The first consideration is whether or not an impoundment is necessary and legally allowed, and then, if so, what its use will be. If it is determined that an impoundment is needed, the next step is to insure that the impoundment is properly designed, operated, and maintained to accomplish its purpose and that these steps are included in the mining plan. The hydrologist will work closely with the engineer during this review to insure that the impoundment is constructed appropriately and that potential hazards, such as overflow and flooding, are minimized. This chapter summarizes concerns associated with impoundments. The hydrologist should refer to the User Guide to Engineering (INT-70) in this series for more specific information on sediment basins.

In what situations would impoundments be found on mine sites?

Impoundments may be developed on mine sites as a result of mining, removal of the mined material (such as coal, bentonite, clay, etc.), or a decision not to fill the mine pits with spoils. They may also be deliberately constructed on mine sites to trap and store sediment.

Discussion:

In situations where impoundments occur on mine sites, the most important consideration is to determine an appropriate end-use for these impoundments, and then to insure that that end-use is effectively accomplished. Possible end-uses for such impoundments are as a habitat, food, and nutrient source for various organisms, such as fish and wildlife; as a drinking water source for livestock and wildlife; as an irrigation water source; and, occasionally, as a human-recreation source. Regardless of what the end-use is, certain characteristics must be monitored to insure that the planned end-use is accomplished: water quality; basin morphometry (shape of the basin and pond bottom); aquatic plants that may occur or be established at the impoundment; and aquatic invertebrates. Depending on the purpose of the impoundment, these characteristics must be anticipated and monitored to assure that the desired end-use is realized. In many cases, it is possible to reclaim the mining area first, then build the kinds of ponds considered to be desirable.

Additional Information:

For detailed information on the characteristics mentioned above, refer to "Limnological Methods," by Paul S. Welch, McGraw-Hill Book Co., Inc., New York, 1948.

In situations where impoundments are deliberately constructed on mine sites, design must be carefully thought through, taking into account a number of considerations. Even before impoundments are planned, however, it must be decided whether they are necessary. In the case of sediment ponds in particular, the hydrologist should determine when reviewing the mining plan whether a pond is a proper alternative. In other words, he should consider whether sediment can be controlled through other means, such as pitting, slope modification, or materials surfacing (discussed in chapter 6); the sediment basin should be utilized where needed, but, in general, should be considered as a last resort.

What factors should the hydrologist consider in determining the adequacy of the mining plan regarding sediment basins?

Generally, he should consider design criteria; the precipitation characteristics of the area; pre-

dictions of sediment load and quality; location of the basin (on-channel or off-channel); volume of material the basin will have to accommodate; desired water-quality standards; safety; maintenance; post-reclamation plans for the basin; and State water laws regarding impoundment of water.

Discussion:

In each situation, site-specific characteristics determine the final design and operation of the sediment basin; final maintenance requirements are determined by the postmining use of the basin—that is, whether the basin will, in fact, be left on the site, or whether it will be removed. Generally, however, basins should be slightly overdesigned because of the uncertainty of hydrologic and meteorologic data. For example, to insure adequate capacity to safely handle a 25-yr precipitation event, the basin should be designed to accommodate a greater volume than the data might indicate was necessary. Safety is a major consideration, since basin failure can create hazardous situations.

When reviewing the mining plan for adequacy of sediment basin design, the hydrologist should use the data available to him to predict as accurately as possible the requirements for the sediment basin. Then, he must work with the engineer to determine whether provisions for meeting those requirements are included in the mining plan.

Chapter 10
POSTMINING CONSIDERATIONS

Chapter Organizer: Grant Davis

Major Contributor: Grant Davis

After reclamation is completed, the Forest Service interdisciplinary team will monitor the mine area to make sure that the reclamation program is effective, and, if problems do arise, to see that they are corrected. If postmining monitoring determines that the mining company has fulfilled its obligation to reclaim the site, then the company can be released from its performance bond. Information provided by the hydrologist will be an important factor in making such decisions.

Since extensive reclamation of minelands has been required of companies for only a short period of time, postmining standards are not very specific. In some cases, such as in coal mining, there are legal requirements, but these are also fairly general. Thus, the land manager will need to set criteria standards for releasing the mining operator from the bond. These standards should appear in detail in the operating plan, although the plan should also include some allowance for variances.

What general principles apply to postmining monitoring?

There are four general principles that should be included in monitoring: the monitoring program should be formulated in the early planning stages of baseline data collection and should be included in the operating plan; monitoring should continue through mining, reclamation and postmining stages; the monitoring program should be adjusted according to the operation phase and data analysis, so that the measurements being taken are cost effective; if any problems are detected through the monitoring program, they should be corrected as soon as possible.

Discussion:

The monitoring plan should be developed to answer specific questions, and it should state what will be monitored and where, who will do the monitoring, how often, and how data will be analyzed statistically and with what methods.

During a long-term operation, different areas of a mine will be in different stages of development. Some areas will not have been mined, some will be active, some will be in a phase of reclamation, and some will be completely reclaimed. Thus, monitoring will occur in different phases, simultaneously.

During the mining and reclamation stages, it might be necessary to include more measurements in the monitoring program than during the postmining stage. As data are analyzed and repeat measurements appear, it might be feasible to reduce the number of items measured, the sampling frequency, and the number of sampling points. For example, if the program originally included monitoring 20 wells, it could be possible to either eliminate certain wells as they stabilize, or to sample them only during periods when the greatest changes are expected to occur.

If monitoring uncovers any problems in reclamation, they should be corrected immediately. Once the performance bond is released, problems that have been neglected become the Forest Service's responsibility.

What factors should be considered during postmining monitoring?

Some of the most important items to consider in a postmining monitoring program are overland flow, streams, subsurface flows, and impoundments.

Discussion:

The water quality and quantity of any discharge from the overland flow should be carefully monitored. A schedule should be set up to include regular monitoring for such items as

streams, wells, and all items listed in the monitoring plan. This schedule should also include visual observation for signs of erosion on the reclaimed area.

When discharge from a mining operation is going into a stream, monitoring should take place both above and below the discharge points. A measurement should also be done on the discharge itself. If a stream has been either reclaimed or relocated, it will need more intensive monitoring, including profiles, information on bedload, bank erosion, and vegetation, as well as the quality and quantity of water in that area.

When monitoring subsurface flows, wells located at strategic points will have been identified in the monitoring program. Checks should be made of water quality, water level, and fluctuations in the ground water level. Other elements that should be measured will depend on the area itself. For instance, if a site has had problems with salinity, or if toxic ions are natural to the area, these items should be monitored. It's also necessary to monitor subsurface flows for seeps, which may come from either overburden or tailings ponds, or in the case of an underground mine, seeps that start to occur as the mine fills with water.

With impoundments, water quality, vegetation that has been established, and sediment buildup should be monitored. If a dam or a spillway is monitored, check for signs of damage or deterioration, such as seeps coming out from below the dam.

What does maintenance management involve once a mine is abandoned?

Once a mine site has been abandoned, such items as impoundments, sediment basins, roads, and diversion ditches must be maintained. Any other structures will also require either removal or maintenance.

Discussion:

As in the development stage, during the maintenance program, the hydrologist will be working in cooperation with the engineer to maintain hydrologic structures. Impoundments, sediment basins, risers, and spillways may all need cleaning or repair. Vegetation on the dam should bychecked regularly and the dam should also be examined for seeps, which are a sign of deterioration.

In the case of roads, items that must be maintained are drainage systems, culverts, including discharge from the culverts, and ditches. Depending on the size of the road and the condition of the area, when bedding down an abandoned road, it may be preferable to remove the culverts and grade the road to the outslope, so there will not be any ditches. If a road is not retained by the mining company, and it has not been accepted by the Forest Service or the County, then it should be abandoned to avoid maintenance costs.

After a mining operation is closed, diversion ditches may also have to be maintained if they go around acid piles or cut through long slopes to break up erosion patterns.

Additional Information:

For more information about hydrologic data collection, refer to Barrett, James and others. 1979. "Procedures Recommended for Overburden and Hydrologic Studies of Surface Mines, Thunder Basin Project." USDA For. Serv. Gen. Tech. Rep. INT-71. (In Press)

For additional information on hydrologic monitoring, refer to chapter 2530 of the Forest Service Manual, "Hydrologic Surveys, Prescriptions, and Plans."

APPENDIX A

GLOSSARY

Alluvium: Material, including clay, silt, sand, gravel, and mud, deposited by flowing water.

Aquifer: A geologic formation or structure that transmits water. Aquifers are usually saturated sands, gravel, fractured rock, or cavernous rock.

Baseline data: Data gathered prior to mining for the purpose of outlining conditions existing on the undisturbed site. Reclamation success is measured against baseline data.

Critical area: An area that should not be disturbed (i.e., mined) because it is deemed extremely difficult or impossible to reclaim.

Discharge: The volume of water flowing past a point per unit time, commonly expressed as cubic feet per second, million gallons per day, gallons per minute, or cubic meters per second.

Environmental Assessment (EA): A report on environmental effects of proposed Federal actions, which may require an Environmental Impact Statement (EIS) under section 102 of the National Environmental Policy Act (NEPA) of 1969. The EA is an "in-house" document of varying degrees of formality; it becomes the final document on environmental impacts for those projects which, because their effects are minor, do not require a formal EIS. Although not formally prescribed under NEPA, the EA is the document normally used to determine whether section 102 of NEPA applies to the project in question and as such, is subject to court challenge if no EIS is filed.

Environmental Impact Statement (EIS): A document prepared by a Federal agency in which anticipated environmental effects of a planned course of action or development are evaluated, as prescribed by the National Environmental Policy Act (NEPA) of 1969.

Erosion: The group of processes whereby earthy or rock material is worn away, loosened or dissolved, and removed from any part of the earth's surface. It includes the processes of weathering, solution, corrosion, and transportation. "Erosion" is often classified by the eroding agent (wind, water, wave, or raindrop erosion) and/or by the appearance of the erosion (sheet, rill, or gully erosion) and/or by the location of the erosional activity (surface or shoreline) or by the material being eroded (soil erosion or beach erosion).

Evapotranspiration: Moisture that is drawn off the soil in the form of a vapor.

Feasibility study: As applied to mining, the feasibility study follows discovery of the mineral and is done by the mining company. Its purpose is to analyze the rate of return that can be expected from the mine at a certain rate of production. Based on this study, the decision to develop the ore body may be made.

Fishery: Any premises upon which breeding, hatching, or fish-rearing facilities are situated when such premises are required to have a license by the State fish and game code, including ponds for commercial use.

French drain: A trench loosely backfilled with stones, the largest stones at the bottom and the size decreasing toward the top. The spaces between the stones serve as a passageway for the water.

Ground water: Water within the earth that is in the zone of saturation where all openings in soils and rocks are filled—the upper surface of which forms the water table; water that supplies wells and springs.

Hydraulic conductivity: The rate of water flow through a porous medium. Also referred to as the coefficient of permeability. Derived from Darcy's Law and expresses flow velocity, v, as the product of the coefficient of permeability, k, and the hydraulic gradient, dh/dl.

Hydraulic resistance: The ability of water under pressure to retard motion.

Hydrograph: A graph showing variation in the water depth in a stream or the volume of water flowing past a point in a stream over a period of time.

Hydrologic budget: An important concept in surface-mine reclamation is "hydrologic budget," which refers to the amount of water entering an area (by precipitation, stream flow, aquifer flow, runoff), in relation to the amount leaving the area (by stream flow, aquifer flow, evaporation, and transpiration).

Hydrologic cycle: The circuit of water movement from the atmosphere through various stages or processes on the ground and then back to the atmosphere again by evaporation and transpiration (also called water cycle).

Hydrolyzation: To decompose a chemical compound by reaction with water.

Impoundment: The accumulation of any form of water in a reservoir or other storage area.

Infiltration: The movement of water into the soil through pores or other openings.

Interdisciplinary team (ID Team): As proposed by recent Forest Service regulations, the interdisciplinary team will be comprised of Forest Service personnel who collectively represent two or more areas of specialized technical knowledge about natural-resources management applicable to the area being planned. The team will consider problems collectively, rather than separate concerns along disciplinary lines. This interaction will insure systematic, integrated considerations of physical, biological, economic, and other sciences.

Laminar flow: Nonturbulent flow of a fluid that has resistance to flow in layers near a boundary.

Land-management plan: According to Forest Service regulations, each forest must have a forest plan, which outlines the most desired and alternative land uses for that site.

Manning's n: An empirically derived estimate of the relative roughness of a channel. Manning's n is used to calculate uniform flow when combined with channel dimensions and channel slope.

Mine road: A road constructed for a mining operation.

Mining plan: Submitted by the mining operator, the mining plan outlines the steps the mining company will take to mine and reclaim the site. The mining plan is submitted prior to start-up of mining operations.

Monitoring: In regard to disturbances caused by mining, the site must be carefully observed by Forest Service personnel to insure that reclamation goals are being met.

Mulching: Placing or leaving non-living material on or near the soil surface for the purpose of protecting the surface from erosion or protecting plants from heat, cold, or drought.

Overburden: Material overlying a deposit of useful materials, ores, or coal, up to, but not including, the topsoil.

Overland flow: The thin layer of water that flows over the ground surface as a result of a rainstorm or snowmelt runoff.

Oxidation: The combination of substances with oxygen. If the substance is a sulfide, this oxidation may result in an acidic conditon.

Patented lands: Land to which a patent has been secured from the Government by compliance with the laws relating to such lands. The patent is a legal document which conveys the title to the ground to the land's owner.

Percolation: The downward movement of water within a soil, especially the downward flow of water in saturated or nearly saturated soil.

pH: Symbol for the negative common logarithm of the hydrogen-ion concentration (acidity) of a solution. The pH scale runs from 0-14. A pH of about 7 is considered neutral. A pH number below 7 is acidic and a pH value above 7 is alkaline or basic.

Piezometric surface: An imaginary surface coin-

ciding with the hydraulic pressure level of the water in a confined aquifer, or the surface coinciding with the water level in observation wells. Contour maps or cross-sections of a piezometric surface or the water table can show the direction of ground water flow.

Precipitation: Any form of rain or snow.

Precipitation index: A table describing the pattern of rain or snowfall.

Recharge: The addition to an aquifer of water that occurs naturally from infiltration of rainfall and from water flowing over earth materials that allow water to infiltrate below the land surface.

Rip-rap: A loose assemblage of broken rock placed to protect soil from the forces of erosion or from movement due to excess hydrostatic forces.

Salinity: The amount of salts in the soil or water.

Sediment: Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Sediment basin: A pond, depression, or other device used to trap and hold sediment.

Slumping: A sudden sliding or sinking of the slopes of a mine dump caused by the ground water reaching a level of saturation.

Snow fences: Temporary fencing composed of thin upright slats used to prevent snow from impeding access to a mine site. Snow fences can also provide a means for accumulating and storing water.

Soil: The loose surface material of the earth, usually consisting of disintegrated rock and a mixture of organic matter and soluble salts.

Spoils: Any dirt or rock which has been removed from its original location by mining operations.

Surface runoff: The moisture that is not absorbed by the soil.

Terracing: Creating a series of raised banks of earth to reduce effective slope length. Sometimes terracing can help prevent severe rill and gully erosion.

Transmissivity (coefficient of): A measure of the permeability of an aquifer. It is expressed in English units as gallons per square feet per day.

Universal Soil Loss Equation: An equation used for the design of water erosion control systems. A=RKLSPC wherein A=average annual soil loss in tons per acre per year; R=rainfall factor; K=soil erodibility factor; L=length of slope; S=percent of slope; P=conservation practive factor; and C=cropping and management factor.

Water balance: A measure of continuity of flow of water, and may be used for any time interval, any drainage basin, or for the earth as a whole. The water balance equation may be written as: E=I-O-S, where E is evaporation; I is inflow, or precipitation; O is outflow, or total runoff; and S is the change in reservoir contents.

Watershed: The total area above a given point on a stream that contributes water to the flow at that point.

Water table: The upper surface of the ground water or that depth below which the soil is saturated with water.

APPENDIX B

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APPENDIX C
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☆U.S. GOVERNMENT PRINTING OFFICE: 1980-0-677-121/87

USDA Forest Service 1979. User guide to hydrology. USDA For. Serv. Gen. Tech. Rep. INT-74, 64 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Summarizes and discusses key questions and rules the hydrologist should consider when working in mining area reclamation. Topics include land-management planning, exploration, and baseline data and the mining plan; surface water; subsurface water; snow management; roads; effects of reclamation on surface water; subsurface water management and treatment; acid mine drainage; impoundments; and postmining considerations.

KEYWORDS: hydrology, mining, mining area reclamation, mining area rehabilitation, land-management planning process.

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THE SEAM PROGRAM

The Surface Environment and Mining Program, known as SEAM, was established by the Forest Service to research, develop, and apply new technology to help maintain a quality environment while helping meet the Nation's mineral requirements. SEAM is a partnership of researchers, land managers, mining industries, universities, and political jurisdictions at all levels.

Although the SEAM Program was assigned to the Intermountain Station, some of its research projects were administered by the Rocky Mountain and Pacific Southwest Research Stations.

MINERAL USER GUIDES

Other User Guides for specialists involved in minerals activities are:

- User Guide to Vegetation, Gen. Tech. Rep., INT-64
- User Guide to Soils, Gen. Tech. Rep., INT-68
- User Guide to Engineering, Gen. Tech. Rep., INT-70
- User Guide to Sociology and Economics, Gen. Tech. Rep., INT-73
- User Guide for Wildlife (planned)
- User Guide for Visual Management (to be published as part of the National Forest Landscape Management Series)

To obtain copies of these guides, write: Intermountain Forest and Range Experiment Station, USDA Forest Service, 507 25th St., Ogden, UT 84401.